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REPORT 44241

TECHNICAL SUMMARY

ARMY-NAVY INSTRUMENTATION PROGRAM

FIXED WING RESEARCH PHASE

REPORT 44241

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TECHNICAL SUMMARY

ARMY-NAVY INSTRUMENTATION PROGRAM

FIXED WING RESEARCH PHASE

(SUPPLEMENT TO ANIP HISTORICAL REPORT NO. 40641A)
PREPARED UNDER CONTRACT Nonr 1076(00)

DOUGLAS AIRCRAFT DIVISION

ACKNOWLEDGMENTS

This report supplements Douglas Aircraft Company Report No. 40641A dated September 1962. Together, the two reports give a historical and technical progress outline of the Army-Navy Instrumentation Program (ANIP).

In its broadest sense, the Army-Navy Instrumentation Program was formulated to make use of the best talents available in industry, universities and research centers. Without the wholehearted cooperation and support of these activities the technical goals could not have been achieved. Many of the contributors of ideas and concepts were not formally or contractually connected with the program. While it is impossible to itemize all of the contributions or name all the associated individuals, the Douglas Aircraft Company is deeply appreciative of their help.

The opportunity to work with the Navy on such a broad and far-reaching program is gratefully acknowledged.

The writers of both reports are deeply indebted to all who rendered assistance directly or indirectly with information, editing and production of the report.

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INTRODUCTION

The Army-Navy Instrumentation Program (ANIP) began formally in 1952 as a Navy Program originally called Integrated Instrument Development (IID) Program. This program culminated approximately ten years of effort by several Navy activities interested in improving man's operational capability in the aircraft. The original terms of reference for the program as summed by the contract were: "The Contractor shall furnish the necessary personnel and facilities for, and in accordance with any instructions issued by the Scientific Officer or his authorized representatives, shall conduct a study on aircraft data presentation. This will be used as a guide to determine the methods of approach, areas to be covered, industrial participants, and methods of coordinating the efforts of all industrial subcontractors. This study will consider the present state-of-the-art of data presentations, as well as all possible new approaches to the solutions of the associated problems." The initial terms of reference remained relatively constant for the Douglas Aircraft Company as coordinator of the fixed-wing phase of the Army-Navy Instrumentation Program from the original contract in 1952 until August 1962 when the coordination function was terminated under ONR contract 1076(00).

This report summarizes the efforts of the Douglas Aircraft Company as coordinator, the work of the subcontractors to Douglas, notes the significant technical achievements of the program and provides a bibliography of technical reports for those whose interest in the technical subjects may be deeper than the summarized survey. This report is the final report of the Douglas Aircraft Company under the noted contract and supplements with technical information the historical information of the program as previously published in Douglas Aircraft Company Report No. 40641A dated September 1962. Discussions of the basic philosophy, organization and operation of the program are minimized herein. Only sufficient historical information is given to orient the reader without reference to the aforementioned historical report.

The last symposium sponsored by the Army-Navy Instrumentation Program was held in September 1959, and no other means has been available for presenting a composite story of program achievements since 1959. It is intended that this report partially fill this gap as well as present a review of the entire program.

It has been the plan of ANIP to form a team of life scientists and physical scientists whose goal can be very generally defined as the determination, via research, of the fundamental facts required for a better understanding of the functional limitations of man and machines in the operation of complex systems. This team worked toward extending the sensory and perceptual characteristics of man, toward improving the man-machine interface, and toward increasing the capability of the man-machine system as a whole.

Accordingly, it has been the intention of the ANIP Coordination Team to develop a research project structure wherein the areas of interest reflected in effort are as broad as feasible within the capabilities and interests of individuals assigned and the funds available. Each research project was a discrete unit of effort, complete in and of itself. The total effort, however, was coordinated or organized on a total man-machine basis. As the individual research program established requirements for hardware or established the facts from which new products could be developed, the information was fed into the systems analysis and systems engineering groups of the team, or into development agencies as applicable. Figure 1 schematically illustrates the way discrete areas of research (sensing devices, computing techniques, human factors, controls, etc.) come together to perform a complex man-machine system.

Research appears as two levels or phases within a program such as ANIP. The first phase involves analytic studies of the requirements of a system and its component units. These requirements begin with the user's operational requirements and extend through information, display, function, environment, configuration, and, finally, material requirements. At this point a complete description exists of the total system, unrestricted by present state of the art.

The second phase takes the requirements as established and the fund of existing knowledge to outline a program for reducing the system to state-of-the-art capabilities. In many instances the requirements and the fund of knowledge are so widely separated that reduction to state of the art is impossible. This gap can be reduced only by research into materials, techniques of manufacture, and physics.

The role of Douglas has been one of advancing systems research on several fronts as shown in Figure 2. Section "A" portrays the program's continuing research necessary to advance the basic man-machine areas and to provide scientific knowledge upon which the second phase, Section "B," is based.

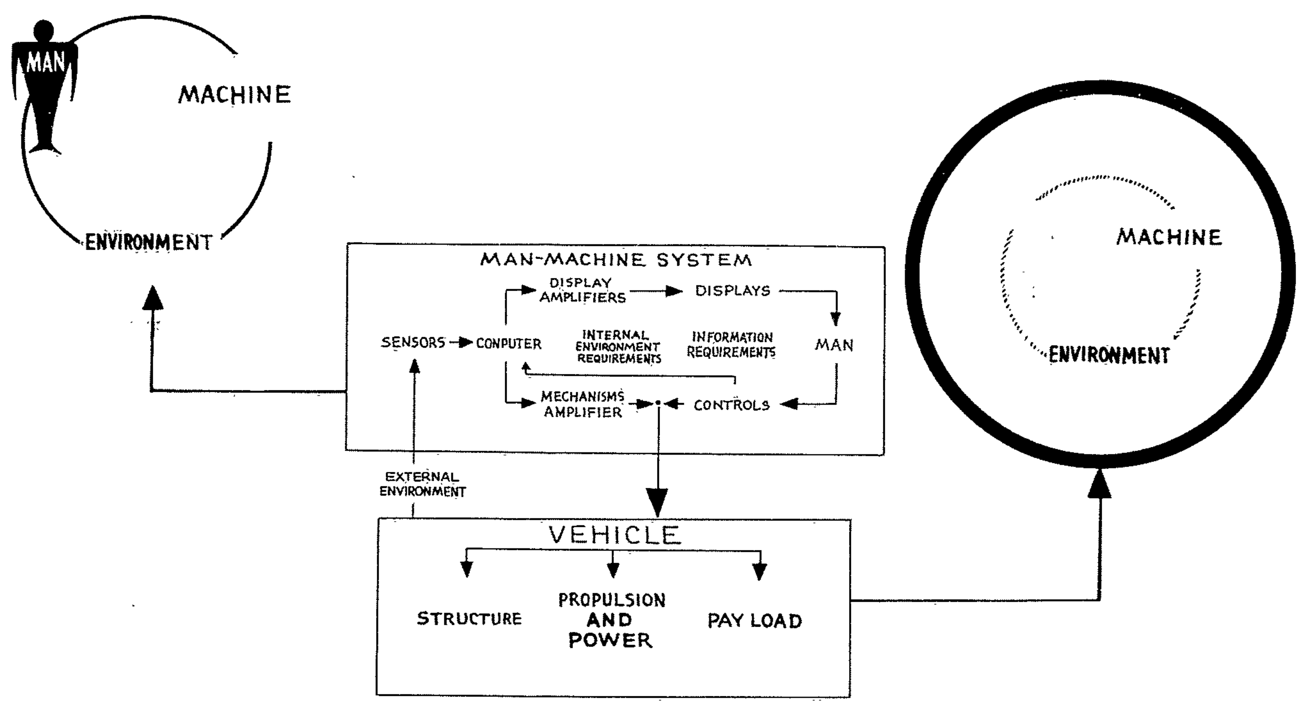
Area "B" indicates systems research activities to synthesize systems that are based upon users' operational requirements. Each system must be analyzed on the basis of tangible information inputs if the system is to have practical significance. Where the operational requirements could not be met by the existing state of knowledge, several requirements were developed to feed back into area "A." The successful completion of a system in Area "B" provided a feasibility report to the developmental agencies, Area "C."

The introduction of all or part of the research into production is a function of development cycle time plus new aircraft availability.

The ANIP in its broadest sense cannot be construed as a medium for product improvement of systems components. Although such products must inevitably result from the equipment prepared to demonstrate feasibility of many program concepts, fundamentally the program has had the continuing need to improve the relationship between the man and the machine. There are many systems within this man-machine framework where the systematic application of directed research can pay large dividends, both in improved reliability and in effectiveness. In addition to the vehicular systems such as aircraft, submarines, space probes and land-based vehicles, there are many business, economic and manufacturing systems which could be so analyzed.

The following sections present, more or less chronologically, the technical aspects of the program. It will be noted that some areas of research received much more attention than others and that some received relatively little attention. Basically, the measures for such priority are the extent of need for new information, techniques or material and the relative importance to the goals of the program. The format highlights the basic areas of research and the contributions of the many agencies that made up the scientific team. In some sections the chronological order has been altered to better convey the problems, accomplishments, and relationships of various activities. The related bibliographic footnote is carried in the marginal column for convenient reference. Only those references that received wide distribution and that can be procured by the reader are entered.

MAN-MACHINE SYSTEMS



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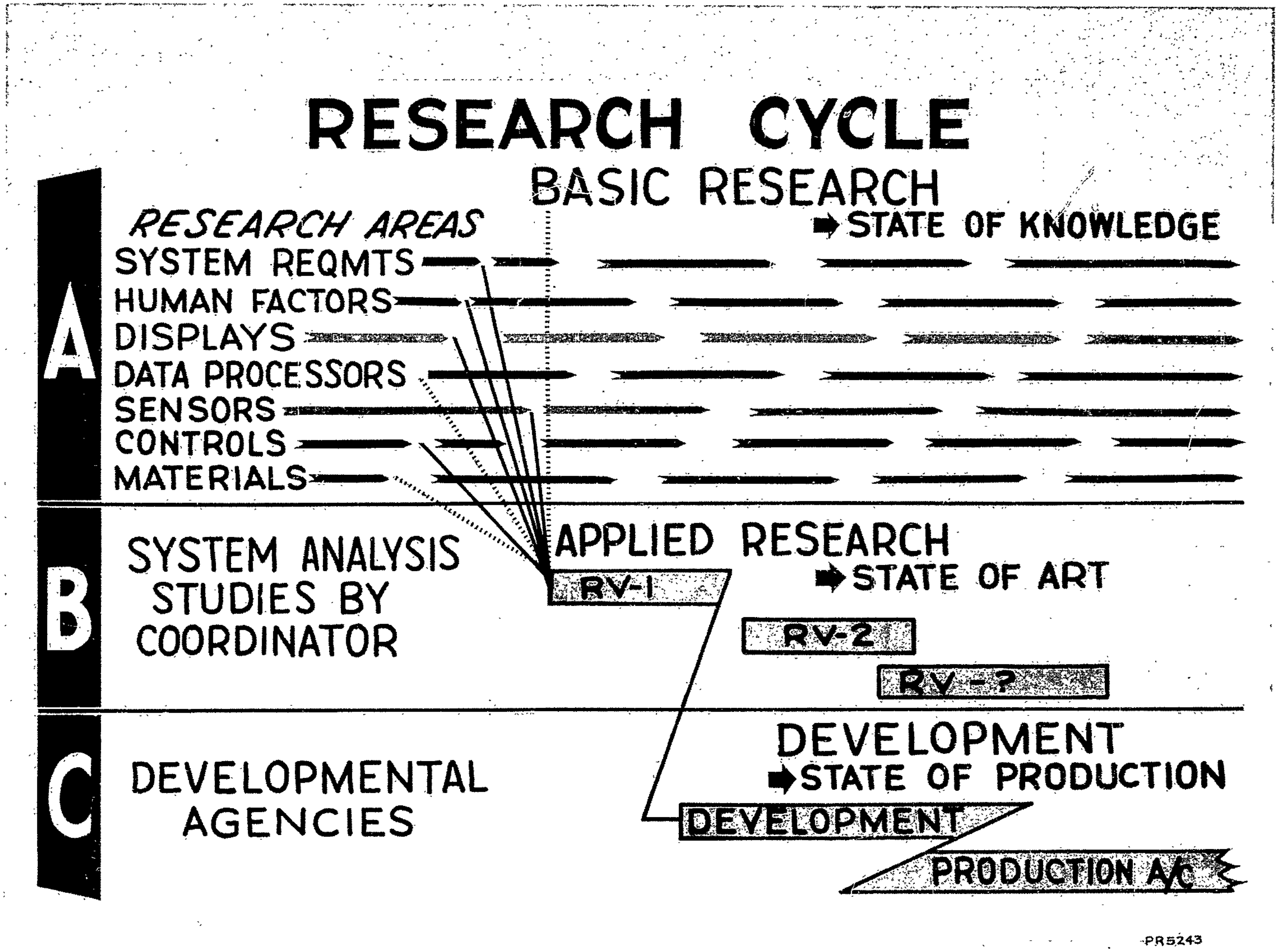
RESEARCH CYCLE
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HUMAN FACTORS

From its inception the Army-Navy Instrumentation Program (ANIP) has maintained the philosophy that the human operator is a critical component in any system loop. And, because of basically unalterable abilities and deficiencies modified slightly through training, the human operator's requirements must be met. This can be accomplished through an effective knowledge and application of human factors research into these man-machine relationships; or, more simply, design the machine to fit the man and the man-machine system to fit the task. A significant point is that man has created devices, systems, tools, etc., to accomplish three important functions: 1) extend the limits of his own basic sensors to better obtain information from his environment; 2) to extend his informational output capability for affecting this environment; and, 3) to facilitate the processing of this information (decision making) to better accomplish his political, economic and philosophic goals.

Before this man-machine interface of display and control equipments could be significantly improved, it was necessary to classify and document what these input and output requirements are as related to a particular task. All-weather single place attack aircraft operation was designated as the task for consideration.

Studies which preceded the formal initiation of the Integrated Instrument Development Program established the fundamental information pilots needed to operate their aircraft. The information was established in basic terms and not in terms which pilots normally read from their instruments. What they needed was direction and not compass heading, for example. Since much of the needed information was available to the pilot in numerical form presented on numerous individual dials and gages, it was apparent that a new approach to the presentation of the information was vitally needed. Pilots can perform their missions with fair success when they are able to see the ground and it was assumed that if the information for instrument flight could be presented in the same basic terms, not necessarily pictorial, then they should be capable of performing as well under instrument flight as under visual flight conditions. A more formal statement of the argument may be stated thusly:

For the closed loop of control and display in a system or vehicle wherein man is an essential dynamic part:

1. It had been practice to introduce a display element to correspond with a given degree of freedom or restraint. Where more than two such correspondences occurred, displays were multiplied, time sharing was considered, tricks of display were utilized, or more than one sense modality was combined to provide adequate information.

2. The result of such an approach was increased eye movement, dispersion, and the learning of a complex scene. The change of any element in the system would, therefore, have to be referred to the learned pattern in order to gain useful meaning with respect to the whole system state.

This process of "integration" of the elemental change with the learned synthetic pattern was a disadvantage incurring loss of time of interpretation, increased error, and loss of comfort. In the case of stress or specific emergency, such disadvantages reduced safety. In all cases, efficiency of the weapon systems can be upgraded by improved data integration.

3. It was believed that the use of a "natural model" would reduce the disadvantages of a totally synthetic, numeric display. This natural model would be achieved by (a) determining those elements in the perceived (in this case, visual) scene which represented the essence of change in the degrees of freedom involved; (b) determining the information required for the control of the derivative (integral, differential) with specific regard to the particular system of vehicle in its operational definition; (c) linking sensors to the display by means of data handling equipment.

4. This natural model would be, therefore, a synthesis of the real world in true dynamic correspondence. It would have high redundancy and it was believed that this would increase ease of interpretability.

5. As a first approach it was believed that an adequate presentation could be derived from three basic displays.

Implementation of the model evolved as:

a. A display of forward view before the operator's eyes, preferably transparent so that the actual world, if available, might show itself in correspondence and add to the veracity of the image. This display would be a real-time and future-time device showing translation and rotation of the axes with respect to a reference plane together with command and imminent items. The display would be created electronically and probably by the use of cathode-ray techniques. It would be, in fact, a synthetic and noise-free window on the forward view.

b. A display of past, present and future derivative information on the ground reference plane and, in the case of the vehicle, of position. This would take the form of a map with vehicle history and current location, and other relevant positional and useful information related to the resultant of axis translation and rotation. It would also show these latter in correct relationship to necessary terrestrial characteristics such as contour, other vehicles, destination, and so on. Command and other selected information was to be repeated from the forward view display on to this planar coordinate display, together with incidentally required data such as range.

c. Displays backing up these two primary displays were necessary since: (1) Some "natural" element changes could not be perceived with sufficient accuracy; (2) Some necessary vehicle or system information could not be reasonably introduced into the natural displays without inconsistency; (3) Some information was specific to system state and could not be related to direct axis or derivative terms of reference.

6. Although primary emphasis was placed upon the development of improved instrument displays, some consideration was given to controls and anthropometrics.

7. Essential questions on a basic level remained to be answered on the original premises:

   a. Is the natural model an advantage in any way over a diversified though perhaps integrated display system?

   b. What is the human mechanism or behavior involved in the interpretation and response to elements of display in a multi-axis system?

   c. What is the difference between the human response to elements referred to a learned non-natural model against the natural model inherent in his everyday life?

   d. If the natural model does show advantage, in what specific ways is it shown; are thresholds changed, are stress and vigilance effects modified, for example?

   e. If the natural model shows advantage, what is the minimum degree of fidelity acceptable in the parameters before performance suffers?

   f. Though some studies have been carried out, what are the critical values for the definition of elements in the displays; how well can the values be read in each parameter with respect to the operational needs of defined systems?

   g. What is the potential use of such displays where the milieu is not in correspondence to learned and reinforced axis and reference states; for example, in space applications and other multidimensional cases?

8. The program, by the nature of the approach taken, accepted the load of the necessary substantiating research and development. However, the greater part of this latter activity would be necessary and applicable whatever the display system used.

Because engineers had given much more attention to machine performance than to the role of the man in the machine, a great deal of information was lacking with respect to pilots of attack aircraft. Since this information was basic, the fundamental precepts of the information presentation, human engineering research was given top priority and specifications for human engineering studies were released immediately after the program was initiated.

The initial phase of the integrated instrumentation program human engineering studies began in 30 September 1953 with the selection of Dunlap and Associates, Inc. of Stamford, Connecticut, as the coordinator of the overall human factors program. The human engineering phase was directed toward the development of a psychologically adequate, integrated display and control system for use in Navy single place attack aircraft.

The research program was divided into six stages, namely: 1) Orientation; 2) Perceptual Cues; 3) Methodology; 4) Simulator; 5) Mockup; and 6) Simulator Test. This investigation was called Phase I of the integrated instrumentation program. Essentially, this phase was concerned with determining the information requirements for various phases of flight and the limitations, through use of simulators and other facilities.

The Douglas Company at this time did not plan a heavy in-house Human Factors effort, but planned to rely on outside contractors and consultants.

During the Phase I program, three subcontractors were assigned responsibility for research in the three basic phases of flight in a combat mission: 1) takeoff, landing, and traffic control; 2) rendezvous and navigation; and 3) strike. Each subcontractor was to investigate, relative to his particular assignment, problems in the six general areas. The three subcontractors were: The Institute for Research in Human Relations, Philadelphia, Pa.; The deFlorez Do., Inc., New York, New York; and General Electric Advanced Electronics Center, Ithaca, New York. Dunlap and Associates acted throughout as the coordinator of the integrated effort.

Upon completion of Phase I, the General Electric Co. of Ithaca was retained to conduct further investigation, with Dunlap and Associates again acting in the coordinating role. Essentially, Phase II consisted of transferring the information requirements (obtained in Phase I) into a form insuring optimal presentation.

The breakdown of the information to be displayed into two basic units, assuming the natural mode as the referent, occurred during this period. One display, the forward looking vertical display, was visualized as providing attitude and command or director information. The second display, the horizontal navigation display, was visualized as providing topological orientation data, cruise control information and other general information needed for long range planning purposes.

Early in Phase II, responsibility for developing the vertical display requirements was assigned to G. E. and the horizontal situation display development to Dunlap and Associates. During 1958, Minneapolis-Honeywell was retained to investigate the human operator as a link in the man-machine system. Douglas Aircraft has continued in-house activities throughout the contract in various aspects of the fixed-wing portion of the Army-Navy Integrated Instrumentation Program, and has gradually expanded its in-house factors capability.

Douglas Report ES 40394, "Summary Report and Planning Document — Human Factors for ANIP," dtd August 1961.

These early years have been covered very briefly only because the information can be found in detail in the Human Factors Summary Report published in 1961. The 48 progress reports of Dunlap and Associates and the 16 of the General Electric group are analyzed in some depth as are other human factors contributors prior to 1961. The following material summarizes the last two years of human factors work.

The bulk of Douglas effort accomplished during the two-year period can be separated into two major areas: (1) the studies dealing with visual and auditory inputs and processes, and (2) the studies concerned with low-level, high speed terrain following capability. If future aircraft are to operate at high speed with minimum terrain clearance, it is necessary to know if the man is capable of performing the mission and how much assistance he will require.

While the design for an experimental study on map information density and alphanumeric orientation had reached the pre-test phase during this period, other studies were initiated: (1) investigation of motion relations on the horizontal display, (2) investigation of various threat evaluation models to meet the increasing prevalence of this factor in the air-to-surface transmission, (3) investigations into the problem of data-link read-in and read-out.

The experimental study on map "information density" was completed and the results presented by Dunlap. As a result, a new chart of the Southern California area was prepared and tested in the Map Plotter equipment in the Douglas laboratory.

A fourth working paper on the "Problems of Degradation of Transmitted Command Data" was published in the fall of 1961. This report was concerned with the breakdown in human communication that inevitably occurred in the high speed semi-automatic data link transmission modes. Research areas were suggested that may alleviate the condition.

General Electric Report, "Visual Factors in the Contact Analog," Cornell University, New York, 1961A.

General Electric continued to pursue visual problems relating to the contact analog display. Two major publications were presented by General Electric Company during the 1960-1961 period: (1) "Problems in Target Recognition"; and, (2) "The Visual Factors in the Contact Analog: A Summary and Final Report."

General Electric Report, "Problems in Target Recognition," Cornell University, New York, June 1961B.

The first report was concerned with the valid presentation of data necessary for target recognition. In this analytical report, a course of action for further research in this area is suggested. The rationale for the program suggested is direct and imbedded in the form constancy hypothesis. That is, there is a tendency to categorize objects as similar under a variety of different and unusual conditions. A familiar circle is perceived as a circle regardless of viewing angle and not as an ellipse as it would be in most cases if physical laws were the only consideration. In order for the same response to be elicited by a variety of stimuli, these stimuli must have some common property or what is known as invariance. These invariant stimuli are the basis for object form constancy. Further, the invariance hypothesis has practical consequence in the design of a form recognition machine. This is for the most part accomplished via an adaptive filter technique. The report presented methods by which a machine of this nature may be constructed utilizing the adaptive filter technique.

The second General Electric report is a comprehensive summary of all work accomplished on the vertical display from the year 1954 to 1961. The document was a detailed and thorough review, starting with the basic design philosophy and working through the many empirical and analytical studies in order to arrive at the 1962 end-product, the vertical display. This display is presently composed of: (1) a textured image that yields orientation information with complete geometric fidelity, and (2) a geometrically true command flight path.

Human Factors Research Report, "First Review of Selected Aspects of the ANIP Program," dtd 1 November 1961.

Human Factors Research Report, "Second Review of Selected Aspects of the ANIP Program," dtd 1 January 1962.

Human Factors Research Report, "Third Review of Selected Aspects of the ANIP Program," dtd 1 March 1962.

The Human Factors Research, Inc. initial contribution was a series of reviews on the ANIP program with a view towards isolating problem areas that required further research or re-evaluation. Their critique was a valuable analysis by a group that had no previous experience or bids generated by close association with ANIP. Three such reviews were published covering the general topics of vigilance and decision processes, visual displays, performance measurement and analysis, performance under stress, human tracking behavior, and monitoring behavior on complex displays. These reviews are excellent source material for future parametric investigations of the ANIP displays.

Shortly after the first review appeared, a contract was let on the experimental study of performance sharing in a dual-mode monitoring situation. The experimental hypothesis investigated was: That an easy vigilance task would be performed better when performed simultaneously with a difficult vigilance task than when it is performed alone. Conversely, performance of a difficult vigilance task would be poorer if at the same time with an easy vigilance task than when performed alone.

Human Factors Research Report, "Performance Sharing in Dual-Mode Monitoring," dtd January 1962.

The independent variables in this study were: (1) type of signal to be detected, i.e., easy vs. difficult, (2) the number of displays to be monitored, i.e., single vs. dual mode, and (3) practice. The dependent variable was the percent detection of each signal type. It was concluded that detection performance on a particular display may be significantly altered by the simultaneous effects of other detection tasks that are concurrently performed. The information obtained from observation of performance on a single display may not provide accurate description of performance on that display when it is included in a milieu of other displays.

Human Factors Research Tech. Memo Report 741-1, "Design Criteria Used in the Development of Contemporary Aeronautical Charts," dtd August 1962.

Two other studies were completed by Human Factors Research, Inc. during this last two-year period. The first was the result of a survey conducted to determine what design criteria are employed by leading cartographers in the design and production of aeronautical charts. These criteria were evaluated for their relevance to the ANIP concept and to possible application in the design specifications for the earth reference component of the horizontal display.

Human Factors Research Tech. Memo Report 741-2, "Geographic Orientation in Humans," dtd September 1962.

The second report dealt with geographic orientation, and the necessity of obtaining a complete psychological understanding of this process before valid design specification can be stated for the horizontal navigation display. In the design of this particular display, it is not possible to substitute electronically generated stimuli for the natural stimuli because geographic orientation is a psychological process by which the individual orients himself to a spatial world that exceeds or transcends his personal experience. Research methodology to explore the nature of the process of geographic orientation was outlined. Further work has been proposed and interest has been evidenced by military organizations in the psychological fundamentals of geographic orientation. There is potential application to the fundamentals of map design.

Since the publication of the ANIP Review of Human Engineering activities, 29 additional documents and studies have been completed under ANIP Sponsorship. Almost one-half of these human factors studies were Douglas in-house effort, while the remainder were split among three subcontractors, Dunlap and Associates, General Electric Company, and Human Factors Research, Inc.

Douglas Report No. ES 40612, "Signal Detection in Noisy Fields: Visual," dtd July 1962.

Douglas Report No. ES 40422, "An Experimental Study of Vigilance," dtd July 1961.

Two related reports on signal detection were completed in mid-1961. The first report surveyed the literature on vision as related to signal detection. The study emphasized the extreme sensitivity of man's eyes, and outlined areas where profitable trade-offs between man and machine may occur. The second report presented a selected review of psycho-acoustics as related to detection, and proposed certain potential areas of improvement in detection capability. Appended to the latter report was an analytical study report on sound absorption in water, and the factors which attenuated the transmission of sound in this medium. These reports are comprehensive and documented with charts and tables.

Douglas Report No. LB 30984, "Signal Detection in Noisy Fields: Auditory," dtd July 1962.

Closely related to the subject matter of signal detection was an experimental study on vigilance. Vigilance as operationally defined is a watch-keeping situation wherein an operator is monitoring a display that reflects a change in the operating environment. The operator's task is to detect and report the absence or presence of this change.

In this study the artificial signal insertion rate, as it affected vigilance or watch-keeping performance, was empirically examined. Although decrement in performance was not demonstrated, there was some evidence that an inverse relationship existed between signal rate and latency of response. The research hypothesis was: The detection of low probability occurring signals in a visual vigilance task situation is a function of signal frequency rate. The independent variable was artificial signal presentation rate. Response latency and percentage signals detected were the dependent variables.

Since it was necessary to draw subjects from a select population (military subjects interested in monitoring or watch-keeping), a mobile laboratory was moved to a university where ROTC students could easily participate as subjects.

Douglas Report No. ES 40408, "An Introduction to the Specification of Optimal Visual Display Design Characteristics," dtd June 1961.

Another study under visual presentation was an analytical report on the visual information handling capabilities of the human. It described the human limitations and capabilities in perceiving the physical qualities, i.e., resolution, intensity, form, contrast, wavelength, size and motion. An understanding and recognition of these visual characteristics is essential to the design of the optimum display for the human operator.

Douglas Report No. LB 30977, "An Investigation of the Effects of Pulsed Lighting Upon Aircraft Displays Relative to the Preservation of Dark Adaptation for Night Flying," dtd July 1962.

Two other experimental studies appeared under this category of visual input. The first was an experimental investigation of the effects of pulsed lighting relative to the preservation of dark adaptation. The rationale underlying the research was that if small pulses of light were presented to the retina, it can be assumed that the eye would be in the dark most of the time. The dark adaptation would be preserved while, at the same time, the brief amount of light would serve to illuminate the information displays.

The research hypothesis for this investigation was: The rate of intermittent illumination on a primary tracking task is instrumental in improving performance on a secondary detection task. The independent variables were pulse rates and intensity of illumination. Dependent variables consisted of: (1) integrated error score on the tracking task, (2) response latency on detecting Landolt rings, and (3) percentage of Landolt rings missed. Results indicate that dark adaptation is preserved with pulsed white light of 5 to 15 cycles per second and an intensity up to 500 foot-lambert-seconds. The light reflected is sufficient to permit adequate visual reception of data.

Douglas Report No. LB 31050, dtd February 1963.

The second experiment referred to above was a study on the effects of control element static friction and force-displacement gradient on a discrete visual tracking task. The research hypotheses were: (1) That force-displacement gradients as well as (a) position on these gradients, (b) direction of movements on the gradients, and (c) pitch regime would affect the force level which an operator would require on the particular side control stick under investigation; (2) That knowledge of the next move would have an effect on the force which the operator will hold on the particular side control stick under investigation. It was the intention of the investigator to deduce from the forces described above a suitable friction band for the particular side control stick under investigation. The independent variables were (a) force-displacement gradient, (b) static friction force, (c) knowledge of the next move, (d) position on the force-displacement gradient, (e) direction of the move along the force displacement gradient, and (f) pitch regime.

The results indicated that static friction band for the particular side-located controller should be between 1.0 and 1.5 pounds; and for precise tracking tasks in pitch, the force-displacement characteristics of the stick should be asymmetric to achieve proprioceptive symmetry.

The importance of terrain following as a tactical operation brought several problems to the attention of the ANIP human factors team. Two simulation studies or projects emerged from the terrain following area of interest. The first of these was the design and construction of a display simulator of airborne electromagnetic sensor. The simulator employed a vidicon camera and very small lens system in conjunction with a reasonably sized three dimensional terrain model to simulate targets, land mass, and cultural areas. This design presented a feasible and flexible solution to the problem of realistic simulation of airborne terrain avoidance systems.

Douglas Report No. ES 40470, "Simulation of Terrain Avoidance Radar Systems," dtd August 1961.

The second simulator study consisted of fitting an available cockpit mockup for the simulation of a low-level, high velocity situation. Flight equations approximating the F5D were derived for flight at 0.95 Mach and an offset of 250 feet above the terrain.

Two study reports relative to physiological feasibility of terrain following activities were prepared. The first report discussed the physiological restrictions imposed by acceleration forces and the fact that these forces essentially define the flight path permitted for the low-level, high-speed terrain following aircraft. The second report discussed the various factors which modified tolerances to accelerative forces in terms of duration.

Douglas Report No. ES 40621, dtd January 1962.

Douglas Report No. ES 40253, "Some Notes on the Physiological Tolerances to Acceleration," dtd February 1961.

The critical question relative to the low-level, high-speed flight is whether the task is within the total capability of the human operator. One of the sub-areas of the above concern is the visual aspect of this flight mode. That is, could the pilot detect and recognize ground targets to a point where it will be worthwhile to employ such missions? If not, then what can be done to aid him so that he can accomplish the task? In order to answer these basic questions, a critical review of the literature on dynamic visual acuity was undertaken. An analytical report, based on this review, set forth both the shortcomings of previous investigations and the suitability of certain areas for further profitable research.

Early in 1961, an experimental investigation was inaugurated in order to determine empirically some basic parameters of dynamic visual acuity. The initial report described a pilot study wherein observers were required to identify moving targets viewed on an endless belt. One of the independent variables was size of aperture through which the belt was viewed. Performance was measured in terms of the angular velocity of the targets past the observer's eyes. The investigator reported significant differences between performance for each aperture size or angular velocity. Additional studies funded by the contractor are continuing.

Douglas Report No. LB 30961, "Dynamic Vision I. The Legibility of Equally Spaced Alpha-numeric Symbols," dtd July 1962.

During 1961, the activities of the existing subcontractors were gradually reduced. However, a small contract was let to Human Factors Research, Inc., a new organization in the program, because of special capability in an area of interest.

The Dunlap and Associates organization continued to explore the visual and perceptual problems of the navigation display in 1960. During this period experimental Dunlap effort was directed toward investigating the legibility of black characters superimposed on irregular gray gradients. This work was primarily directed toward design specifications for the horizontal situation display and was oriented for presentation by means of television. A scaling study of various aircraft symbol silhouettes was also made during this period in order to discover if there were any basis for classifying them as friendly, most friendly, enemy-like, and so on.

Aircraft Information — Exchange Requirements: A Projection for 1966–70. Dunlap and Associates (Secret), dtd June 1961.

Other work accomplished during this period was the revision of a map to be used in a study investigating the "packing" of information for a video display. Aside from this study, a large proportion of project effort was directed toward this field work on an information-exchange study. Data were gathered on site at various Naval fleet operations to study and classify the voice message and other information exchange during aircraft tactical maneuvers. Additional reports were prepared in the following areas:

1. Problems of Decision Making

   In this report Dunlap explored areas relative to decision making as it might apply to the ANIP concept.

2. Visual Aspects of Aerial Collision Avoidance

   This report presented an analytical study of factors contributing to mid-air collisions. These factors were grouped into the following categories: (a) collision due to non-detection by one or both pilots, (b) aircraft turning to avoid collision and turning into each other, and (c) misjudgment of distance and speed due to certain causes.

3. Problems of Language and Message Entry Devices for Air-to-Surface Communication Systems

   Two major system design approaches were suggested as areas for potential research in the air-to-surface communication problem. Most such communications must be accomplished by semi-automatic devices which by nature reduce the pilot's flexibility of expression.

The objectives were to improve the communication network from both the operator and equipment standpoints. Progress was reported by Dunlap on an experiment designed to test horizontal display readout performance under controlled conditions of map density and orientation. Special maps and map holders were in various stages of construction.

SYSTEMS ANALYSIS

This term, systems analysis, is certainly as broad in interpretation as any term in contemporary technology. The identification used here is more precise. However, the scope of the effort within this category has been very broad during the preceding ten years of Army-Navy Instrumentation Program (ANIP) research. It was evident in the early months of the program that research to improve the man-machine interface — i.e., display — could not succeed without a thorough study and ultimate improvement in the supporting equipments. A best-display hypothesis would never materialize unless the human factors investigators were provided with tools for experimentation and the developmental agencies provided with feasibility models of the required equipments. Therefore, systems analysis research was chartered with these objectives: to reduce the operational desires of the customer to a form or classification that would permit man-machine systems requirements and finally the system equipment to evolve. Human requirements were paramount and would not be compromised for the long range goal.

The general area of systems analysis is considered, therefore, to include all work concerned with the specification of the system requirements, either in part or in total. As a result, the spectrum of systems analysis work ranges from operations and feasibility analyses to detailed specification of the requirements pertinent to the total system involved. This entails development of the man-machine functions, specification of a compatible man-machine interface, and incorporation of necessary state-of-the-art compromises. Most of the systems analysis work has been carried out at Douglas as part of the coordinator's in-house effort, in order to fulfill requirements of being knowledgeable in the state of the art and defining areas for research. However, significant contributions in this area have also resulted from subcontracted work at Lear, Inc., Melpar, Inc., and Federal Telecommunication Laboratory. The following chronologically arranged commentary and annotated bibliography summarizes the ANIP systems analysis program in the fixed-wing phase.

Douglas Report ES 17263, "Feasibility Study of Integrated Presentation of Flight Information," dtd 25 March 1953.

The coordinator's initial task was to study the requirements for an adequate cockpit display-control system for presentation of flight information and the feasibility of an integrated system which would satisfy those requirements. From the beginning, the ANIP approach became identified with: "establishment of feasibility preceded by a detailed analysis of requirements."

Douglas Report ES 17374, "Mock-up of an Optimum Cockpit Layout for a Minimum Weight Airframe" (Confidential), dtd 22 June 1953.

As an adjunct of such feasibility studies, the program Scientific Officer at ONR specified that instrument design studies would be conducted and that mock-ups of indicated instrument arrangements would be constructed. Accordingly, a full scale cockpit mock-up was designed and built to demonstrate an optimum cockpit layout for a minimum weight airframe. The instrumentation involved was designed to satisfy three separate and distinct operational goals:

- a simplified attack plane
- a minimum requirement attack plane
- a long-range development all-weather attack plane

Instrumentation for the first and second operational goals consisted of existing instruments or experimental models. Instrumentation for the third operational goal illustrated one approach to the ultimate goal of carrier all-weather flight. In this last arrangement, only the standby instruments were physically in existence at that state of the art. The majority were initial expressions of what might meet the operational and display requirements.

The coordinator's primary responsibility involved definition of the problem areas. This done, it became necessary to screen and select recommended specialists from industry and the academic world whose qualifications marked them as desirable recruits for the envisioned effort. With selections finalized and work progressing, emphasis shifted to coordination for maximum effectiveness of the wealth of rare talent which the program had attracted.

In keeping with the hypothesis that the man is the significant, if sometimes ineffective, link in aircraft operations, initial source material for the system requirements came from human factors research efforts. A basis of analysis common to both man and machine was sought to enable the total man-machine system to be considered as an entity. This common denominator is information. The system requirements could best be described in terms of the information exchange that takes place between the man and the machine, with reference to their environment and the task to be performed.

Accordingly, preparations were made to launch the necessary specialized efforts through subcontract. Specifications were prepared and distributed to interested companies and proposals on these specifications were solicited. The specified studies provided for detailed investigations which would establish feasible means of satisfying the cockpit display requirements of all-weather flight. The responding proposals were evaluated and contracts were placed with Lear Inc., Melpar Inc., and Federal Telecommunication Laboratory to study, respectively, the areas of Normal Flight, Navigation and Rendezvous; Takeoff, Landing and Traffic Control; and Strike. These groups were to analyze the basic operational and informational requirements of the pilot during these selected phases of flight. Recommendations for further study of key problems were included.

Douglas Specification 7530321, "Feasibility Study Spec. I—Strike Phase," dtd 12 May 1954.

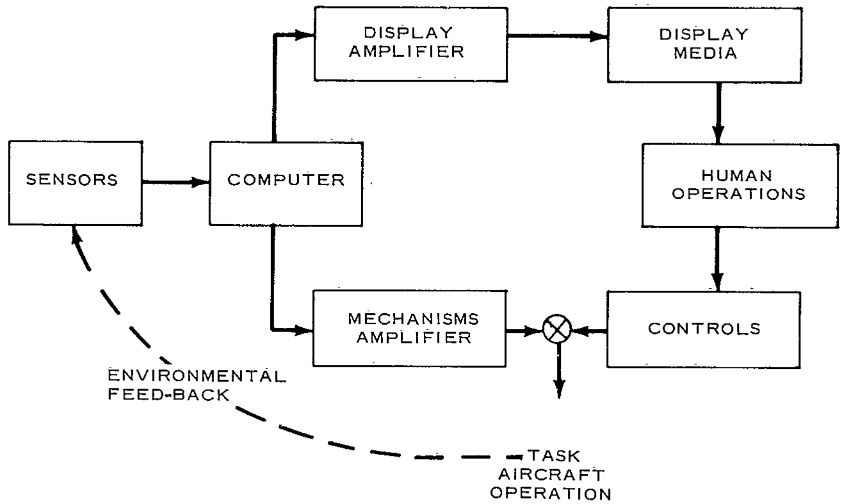
Douglas Specification 7540322, "Feasibility Study Spec. II—Takeoff, Landing and Traffic Control," dtd 17 May 1954.

Douglas Specification 7540323, "Feasibility Study Spec. III—Navigation and Rendezvous," dtd 12 May 1954.

Lear, Inc. Report, "Feasibility of Design; Data Processing Network," dtd 5 January 1955.

Lear, Inc., Quarterly Progress Report dtd 21 January 1955.

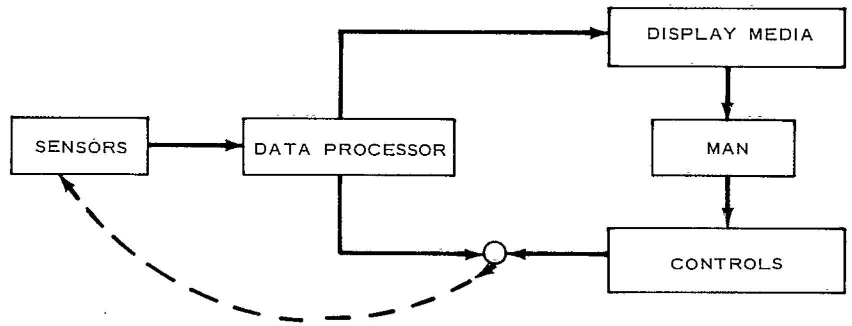
Another effort to simplify and consolidate thinking about man-machine problems was the creation of the man-machine pictogram that schematically identified the basic system elements. For this purpose, the system was envisioned to be constructed of the following basic functional blocks.

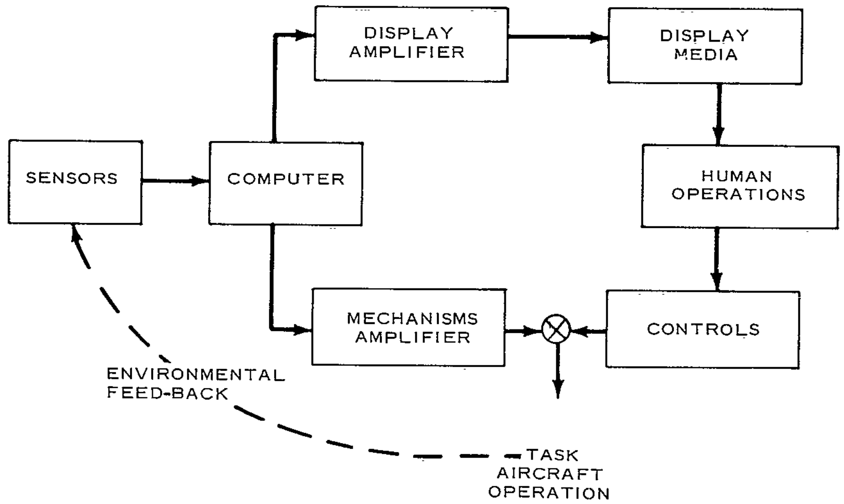


Melpar, Inc., Quarterly Progress Report No. 1, covering period 16 November 1954 through 16 February 1955, dtd 8 March 1955.

Federal Telecommunication Laboratory Progress Report No. 1 (Confidential), covering period 7 January 1955 through 6 March 1955.

In later discussions, the man-machine pictogram evolved to the simpler form shown below by considering amplification as a data processing function along with computation:





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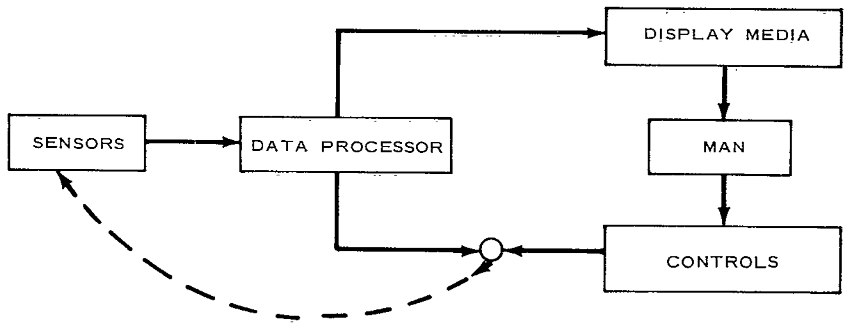


Lear, Inc. Project Status Report for Coordination Meeting, Washington, D.C., 26 March 1955.

Lear, Inc., 2nd Quarterly Progress Report, dtd 3 May 1955.

This viewpoint established an important communication link between the coordinator and the research subcontractors so that the boundaries of the various disciplines could be defined. This format helped determine the direction of flow of information in the system and the counter-flow; that is, the functional requirements.

While Douglas analysis efforts attempted to determine the information requirements and so permit explicit studies to be conducted for each man-machine block, exploratory specifications were created and distributed for new ideas in these areas. These implementation studies are summarized briefly in the subsequent sections of this report.

Crew survival and flight safety also received the benefit of the systems requirements approach, and the concept of a universal ejectable cockpit section, then under study by Douglas, resulted. This cockpit section would house the most expensive system components (including the man) in a controlled environment, and would afford a safe means of in-flight vehicle abandonment. At the same time pilot error factors, crew training requirements, and cost would be minimized by the use of a standardized design. This concept was not developed further under the ANIP but has since been the subject of considerable investigation sponsored by other Government agencies.

Melpar, Inc. Quarterly Progress Report No. 2, covering period 16 February 1955 through 16 May 1955. dtd 17 June 1955.

With completion of the Lear, Melpar, and FTL Studies in early 1956, a more precise definition of the problem areas became available to the coordinator.

Lear, Inc. Progress Report, dtd 20 June 1955.

Federal Telecommunication Laboratory Quarterly Report No. 2, covering the period from 7 March 1955 to 6 June 1955.

Lear, Inc. 3rd Quarterly Progress Report, dtd 16 August 1955.

Federal Telecommunication Laboratory Quarterly Report No. 3, covering the period from 6 June 1955 to 10 October 1955.

The Lear study analyzed the tactical requirements pertinent to their assigned flight phases in order to define the fundamental sensing measurements to be made. Natural phenomena were examined as sources of these measurements, and existing systems and sensors were analyzed to determine their adequacy in this regard. Equations for navigation on the earth, maximum range, maximum endurance, best cruise speed, and best cruise altitude were formulated. Areas of required research and development were found to be sensing for thrust, high Mach number, angle of attack, fuel mass quantity, and inertial reference systems.

Lear, Inc. Progress Report, dtd 7 November 1955.

Douglas Report ES 26141, "Standard Ejectable Cockpit Capsule" (Confidential)

Douglas Report ES 26258, "Preliminary Feasibility Summary Report," dtd 14 January 1956.

Federal Telecommunication Laboratory Report No. 993, "Final Report — Strike Phase Feasibility Study."

The Melpar study concluded that the findings regarding optimum path determination and instrumentation requirements for landing are also valid for the takeoff phase of flight. These two flight phases were covered by a formulation of expressions for attitude as the aircraft followed a given trajectory and by the mathematical synthesis of the contact analog display. Areas of required research pertinent to these flight phases were given as height above terrain, aircraft attitude, and ground range during the final approach — all associated with the mathematics of the contact analog display. A possible implementation of the required landing display was described. The traffic control phase of the study involved examination of the means by which the requirements of safe separation of aircraft, expeditious traffic flow, and adequate traffic flow control could be fulfilled. A method was formulated for determining the required separation

interval between aircraft, required length of the approach track, and holding patterns. The bandwidth and scanning requirements of a pictorial display for maintenance of safe separation were also examined. The concept of a Strike, Rendezvous, and Anti-Collision Radar (SRAC) was developed from these considerations.

The Federal Telecommunications Laboratory study proceeded from a careful definition of each tactical objective of the specified flight segments in order to establish the fundamental information inputs required by the man-machine system. These definitions included the mathematical expression of the relationship between the motions of the target, the aircraft, and the weapon. Known natural phenomena were then analyzed as sources for the information inputs. Further study of the tactical requirements of target assignment were recommended. Sensor areas deserving further research were given as fuel quantity, air density, and air temperature. Additional study was recommended on electromagnetic transmitters, receivers, and antennae. The need to reduce sensor sensitivity to temperature change, especially with regard to inertial sensors, was emphasized.

Melpar, Inc. Final Report, "Feasibility Study of Flight Information Processing System for Takeoff, Landing, and Traffic Control," dtd 23 January 1956.

Federal Telecommunication Laboratory Report No. 997, "Special Summary Report — Strike Phase Feasibility Study" (Confidential) dtd 12 March 1956.

Lear, Inc. Report, "Summary of Work Performed — Feasibility Study, Normal Flight, Navigation and Rendezvous Phases," dtd 14 March 1956.

Lear, Inc. Report, "Final Report — Feasibility Study Normal Flight Navigation and Rendezvous," dtd 25 April 1956.

Efforts to prove the feasibility of an entire system as analyzed, studied, designed, and built with results from Douglas and subcontractor research led to early establishment of a contemplated series of research vehicles. These research vehicles (designated RV's) were to be constructed periodically throughout the program when sufficient progress had been made in the entire man-machine system to warrant their existence. Each element of the man-machine system would be represented. This total system feasibility demonstration was to provide a necessary bridge from the research to the development. Development programs could then be started by the user agencies (BuWeps and Army Signal Corps) leading to possible production. This research cycle would maintain the proper balance between basic and applied studies in equipment components and in human factors.

Douglas began design analysis for the first RV-1 in 1955 after significant progress had been made to that date. (The RV-1 operation and results are summarized in the Simulation and Test section.)

RV-2 studies were started in the fall of 1957 during the terminal phases of RV-1 flight operations. The creation of specific research vehicle performance criteria even when the vehicle was only a "paper" replica of a user aircraft requirement, permitted the study, heretofore unrestrained, to be definitely delineated. It enabled the user agencies to identify in a much clearer fashion the output of research in terms of their current operational problems.

RV-2 studies culminated in an analysis and report. No actual vehicular test effort was brought about before the close of program with Douglas.

The coordinator's concurrent feasibility studies directed toward an RV-2 consisted of investigations into the following areas:

- Display construction: The perspective transformation of the computed three-dimensional model to the two-dimensional display plane.
- Flight path specification: The computations required to construct the mathematical model of the flight path in three dimensions.
- Re-examination and comprehensive documentation of all previous studies of the pilot information requirements.
- Terrain clearance and obstacle warning.
- Aircraft dynamic performance analysis techniques. This work involved investigation prerequisite to the issuance of a specification and preparation of the specification.
- Map projections suitable for use in the horizontal display.
- Optimum flight path synthesis.
- Acoustic noise.
- Communications requirements.
- Systems integration analyses; i.e., analytical studies undertaken to determine the most feasible means of implementing an experimental system which would reflect the conclusions reached in the host of companion studies then underway. The system was designated RV-2 (Research Vehicle—Number 2).
- Computer functions pertinent to the horizontal display intended for the RV-2. This study established what the central computer would have to do to support the horizontal display and formulated the general equations describing these functions.
- Preliminary systems analysis of the RV-2. This study established the basic man-machine division of tasks for the RV-2 and systematically circumscribed the system to arrive at a preliminary equipment list and specification of system capability.
- Storage requirements: This included the scan conversion problem which arises when transforming radar data to TV (raster) displays.
- Engine power display requirements.

Where study data volume did not warrant an individual report on each of these research areas, those results were reported in a summary report covering the long range feasibility studies.

Douglas Report ES 26724, "The Equations of Motion of a Discrete Point Projected from the Ground Plane to the Display Screen of an Aircraft," dtd 17 July 1957.

Douglas Report ES 26840, "Pilot Information Requirements," dtd 9 October 1957.

Douglas Spec. 7672750, "Spec.—Dynamic Performance Analysis, Study of," dtd 26 February 1958.

Douglas Report ES 27068, "An Analytical Analysis of Length Distortion in Five Universally Applicable Map Projection Types," dtd 10 May 1958.

Douglas Report ES 27116, "Acoustic Noise Problem Referred to Naval Aircraft," dtd 13 May 1958.

Douglas Report ES 29270, "Presentation of Objectives for and the Proposed Implementation of the RV-2 System," dtd 23 January 1959.

Douglas Report ES 29286, "RV-2 Horizontal Display Computer Functions," dtd 30 January 1959, Rev. 24 January 1961.

Douglas Report ES 29301, "ANIP RV-2 Preliminary Systems Analysis," dtd 13 February 1959.

Douglas Report ES 26842, "Summary Report—Long Range Feasibility Studies," dtd 17 February 1959.

Douglas Report ES 29307, "A Suggested Research Program for Evaluation of ANIP in a Modified Human Centrifuge," dtd 23 February 1959.

Douglas Specification 7679878, "Spec.—Energy Transfer Functions," dtd 24 February 1959.

Douglas Report ES 29325, "Fundamental Requirements for Generating the Vertical Display," dtd 13 March 1959.

The coordinator continued the analytical effort in support of the RV-2 and the ANIP systems objectives in general. This included surveys of means to experimentally evaluate ANIP display concepts; studies aimed at facilitating system integration through improved data processing techniques; dissemination of information on the ANIP methodology to assure maintenance of the systems approach; and, the necessary mathematical formulations relative to implementation of feasible systems.

Douglas Report ES 29329, "The Equations of Perspective Transformation of a Line or Set of Parallel Lines from a Reference Plane to a Display Plane," dtd 13 March 1959.

Douglas Report ES 29582, "Bombing Equations Required for ANIP RV-2 Research Vehicle," dtd 11 April 1959.

Douglas Report ES 29306, "Cruise Control and Fuel Management RV-2 System," dtd 23 May 1959.

The results of a considerable amount of this work served to influence subcontracted efforts in progress at that time. This influence was manifest in contemporary specifications, contract amendments, and coordination contracts.

Throughout all of the analytical work on the RV-2 System, continual reference to the established requirements assured continuity and compatibility. For example, insofar as practicable, each subsystem and component was subordinated to the total system to facilitate achievement of a truly integrated man-machine complex. It is believed that the developmental and production implementation of the results of this study would amply demonstrate the soundness of this approach.

Douglas Report ES 40466, "Recommendations for RV-2 Sensor Requirements" (Confidential) dtd 24 July 1959.

Douglas Report ES 29527, "Navigation Equations Required for ANIP RV-2 Research Vehicle Implementation," dtd 21 August 1959; Rev. April 1962.

Douglas Report ES 29673, "Airplane Equations of Motion for RV-2 Computer," dtd 14 January 1960.

Douglas Report ES 29796, "Suggested Flight Research Study of Army-Navy Instrumentation Program Concepts," dtd 15 March 1960.

As the RV-2 system took form on paper, the subcontracted efforts involving equipment became more precisely focused on the common goal. Thus, work in the computer and display generation areas began to merge and develop interface problems. Research to achieve a solution to these problems had been undertaken for only a short time when funding limitations dictated a reduction in the level of effort. At this point it became apparent that the RV-2 would not be implemented as an experimental system but would, instead, be terminated with the analytical study phase. Anticipating the possibility that other analytical studies of this nature would follow, it was considered advisable to identify these design study systems as "airborne research systems."

Douglas Report ES 29980, "Man-Machine System Methodology," dtd 30 August 1960.

Accordingly, the summary report on the RV-2 systems analysis effort was issued as the "Airborne Research System, a Study for the Fixed Wing, General Attack Mission." This report describes the complete evolution of the system from the preliminary requirements analysis through the resultant man-machine system.

Douglas Report ES 40353, "A Brief Study of Some of the Economic Advantages of Continued R&D of the ANIP," dtd 2 May 1961.

Through subsequent systems analysis work, Douglas has attempted to consolidate the RV-2 computer functions still further and initiate work in the area of ground modes. The former would be done by reducing all RV-2 equations to basic elements and operations and then tabulating these exploded equations in an integrated data flow chart. This was done and described in a report called "Computer Preprogram Analysis." However, the report remains unpublished since termination of the prime contract precluded the necessary final check and correction of the mathematics involved. A review of the turbojet cruise control

Douglas Report ES 40026A, "ANIP Airborne Research Systems – Fixed Wing, General Attack Mission," dtd 9 August 1961.

Douglas Report ES 40631, "Computer Preprogram Analysis," dtd 9 March 1962 (Unpublished).

Douglas Report LB 31183, "Cruise Control of Turbojet Aircraft," dtd 21 January 1963.

problem undertaken in conjunction with this preprogram analysis was completed and provides a comprehensive treatment of the power plant control-display problem. The purpose of the ground modes study was to categorize the functions common to ground/deck handling of aircraft as a preliminary to a rigorous man-machine systems analysis. In other words, the object was to provide a ground/deck operations equivalent of the "Pilot Information Requirements" from which detailed analyses could proceed. It was hoped that the detailed analyses would indicate means of achieving an optimum system for ground crews — i.e., standardized and simplified ground support equipment, maintenance, and logistics requirements.

The Douglas system analysis research provided the basic requirements from which research proceeded in machine system areas that are discussed in Sections 4 through 8.

A compendium of the major system analysis reports provides essential data about the ANIP methodology. Synthesis of future systems can result.

DISPLAY MEDIA

The man-machine system area of display media is considered to be the device or devices that accept as an input energy in some form from a data processor or other source and provide as an output a visual or auditory presentation informationally and physiologically acceptable to a human operator. This energy transduction must meet the input requirements of the human. Major contributions in this area were made by Varo, Inc., Kaiser Aircraft & Electronics, and Servomechanisms.

Douglas Specification 7446947, dtd March 1954.

Varo Final Report and Design Data, "The Varo Headsight," dtd March 1955.

The initial attempt to improve presentation of information to a pilot rested upon the practical assumption that basic referential elements could best be supplied by a view of the outside world. Other symbology could be superimposed on this view by means of the Headsight (a helmet-mounted 1" cathode ray tube). Weapon delivery and orientation information could also be thus visually presented. Varo reported the feasibility of this approach and reinforced the concept of adding information to the real world in a natural context.

Douglas Specification 7449950, "Flight Data Display Component," dtd 23 March 1954.

Human Factors and system feasibility studies were supporting the "Contact Analog" philosophy of display. To present this data to a pilot, a larger, less restrictive means of display was required than afforded by the Headsight. A specification was released to 65 companies for a flat, transparent medium. Out of eight proposals, the Willys Motor (later Kaiser Aircraft & Electronics) idea for a flat cathode ray tube appeared the most promising. Laboratory model of a flat tube was developed by Willys and delivered to Douglas for demonstration of feasibility. The device was a non-transparent flat tube constantly pumped to maintain the internal vacuum. This feature permitted the tube to be opened for altering or servicing the internal structure.

Douglas Specification 7547986, "Display Tube – Thin Display."

Douglas Specification 7548720, "Navigation Display Tube."

Successful demonstration of non-transparent flat cathode ray tube (CRT) using the Aiken deflection principle prompted the writing and distribution to Kaiser of two specifications for the development and fabrication of a vertically oriented transparent tube for display of the "contact analog" and a horizontally oriented unit for navigational and tactical planning data.

The demonstration had indicated the feasibility of the deflection method and the general principle. Left for development were primarily the tube physical structure, the sealing of such an envelope, the technique for switching the deflection plates, and finally, the transparent phosphor.

In a series of twenty-two progress reports, the problems and solutions to these areas of study were described by Kaiser. These quarterly reports covered the period November 1955 through February 1961. A cross reference chart indicates the frequency of effort on various phases of this work (Table I).

TABLE I.

APPLICABLE QUARTERLY PROGRESS REPORT NUMBER INDEX
(KAISER AIRCRAFT & ELECTRONICS)

AREA OF TECHNOLOGY	REPORT NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
GLASS FORMING				●						●		●	●		●	●	●	●		●	●	●		
TUBE SEALING				●	●	●		●			●	●	●	●	●		●				●	●		
ELECTRICAL FEED-THROUGH						●								●	●	●	●				●			
ELECTRON BEAM DYNAMICS								●	●			●	●	●	●	●	●	●	●		●	●		
PRIMARY DEFLECTION									●	●	●						●				●	●		
SECONDARY DEFLECTION						●											●	●			●			
DISPLAY SURFACE (PHOSPHORS)									●								●		●		●	●		
VERTICAL SWITCHING							●		●	●	●	●	●	●	●	●	●	●	●	●	●	●		
HORIZONTAL SWITCHING					●	●	●	●	●	●	●		●	●	●	●	●	●	●		●	●		
ASSEMBLED TUBE TESTING								●												●		●		
VIDEO GENERATION (Ref Sect 5)	●	●	●	●	●	●	●	●							●									

Kaiser Quarterly Progress Report No. 4, dtd November 1955.

The initial problems were in the area of the fabrication of the glass envelope. Being a flat, thin, evacuated glass form, it did not represent the ideal structure; conventional high temperature sealing techniques would damage the phosphor in the device as originally proposed, so new techniques were developed.

Two approaches to the glass envelope were explored. First, the 2½-inch-thick tubes were molded to shape, one half at a time. The molds were costly. However, there was only one joint between the two halves to seal. The second technique utilized two pieces of optically flat plate glass separated by a ring bent from similar material. These three pieces were then fritted (glass-soldered) together.

Kaiser Quarterly Progress Report No. 5, dtd March 1956.

The molded envelopes were obtained from Kimble Glass Company. Kimble's method of sealing was successfully used and several assemblies endured a 3-atmosphere pressure check. Program budget limitations precluded pursuance of work on both molded and plate glass envelopes. Initial success of the "molded envelope" concept, plus the availability of molded blanks, encouraged further work on this process.

Kaiser Quarterly Progress Report No. 6, dtd May 1956.

As tube blanks were received from Kimble, Kaiser experimented with the Corning glass-solder technique and found it to be as successful as Kimble's with the added advantage of lower sealing temperatures. Facilities at Kaiser favored this technique. All sealing operations could be accomplished there without subcontract assistance. Both "windshield" and "navigation" tube shapes were fabricated and tested.

This experience in sealing provided an opportunity to study materials and means of passing electrical leads through the fritted joint. Stainless steel proved to be superior to the other materials tested.

Kaiser Quarterly Progress Report No. 8, dtd November 1956.

As tubes were accumulated, several were delivered to Douglas preliminary to installation in the T2V flight test aircraft. Additional tubes were subjected to vibration testing at Kaiser for both experimental evidence and to insure safety for the forthcoming flight program at Douglas.

Frequency and "G" spectrums ranged from 10 to 500 cps and 2 through 10 "G." First extensive failure occurred at 7.5F when the spring clips centering the internal deflection assemblies loosened with resultant loss of rigidity of the structure. At 10G the glass plates supporting the deflection assembly broke.

Kaiser Quarterly Progress Report No. 9, dtd February 1957.

As a result, a more substantial mount for the deflection assembly was designed, using ceramic and Mycalex plates.

A further improvement — increase in the tube yield — was realized with incorporation of a new acrylic resin, developed by Dupont, as binder in the glass solder.

Douglas Specification 7559297, dtd June 1957.

Douglas Specification 7559298, dtd June 1957.

The successful flight of a "windshield" type tube in the T2V test aircraft at Douglas encouraged the release of two new specifications for 3 sets of improved tubes of a slightly different shape and utilizing the plate glass assembly method.

Kaiser Quarterly Progress Report No. 12, dtd November 1957.

Use of a new sealing oven at Kaiser produced a higher (50%) yield than experienced with previous tubes. A longer, more gradual heat soak and cooling at 1°F per minute allowed glass panels to be stress relieved. The results were less cracking and lower residual stresses at room temperature.

With the return to pure tube research from some development for the T2V and ANIP symposium efforts, the work on the plate glass tube was resumed. Potentially stronger, cheaper, optically less distorted, this technique should provide a more dependable envelope and an approach to production feasibility. Optically flat sheets and spacer rings were procured from Pittsburgh Plate Glass Company and joined with high temperature solder glass at Kaiser.

Kaiser Quarterly Progress Report No. 13, dtd February 1958.

Kaiser Quarterly Progress Report No. 14, dtd May 1958.

Kaiser Quarterly Progress Report No. 15, dtd August 1958.

For almost a year experiments using both soft and tempered plate glass and several varieties of glass solder were conducted. The processing program was varied by changes to pressure, heat, and time values. Thinner tube using plates of tempered glass were tried. First ½ inch, then $^5/_{16}$ inch plates were used in an attempt to cut tube weight.

Kaiser Quarterly Progress Report No. 16, dtd November 1958.

Kaiser Quarterly Progress Report No. 17, dtd February 1959.

Kaiser Quarterly Progress Report No. 20, dtd November 1959.

Kaiser Quarterly Progress Report No. 21, dtd February 1960.

Thinner separator rings were tried and found to aid in absorbing stresses from the face plates. A new technique of electrical feeds was initiated to help reduce stress on the envelope and also insure a better seal. Silver powder was mixed with glass solder and painted on the joint at appropriate places; the glass solder was used elsewhere. A .05 inch thickness was adequate to provide for electrical currents involved.

Work on the envelope was gradually reduced due both to the success of experiments and phosphors. A limited fabrication test program continued until the end of the contract in 1961. Further problem solving would have to await a serious production development program when the tubes would be applied to a production system.

The second critical area in the development of the flat tube was the solution to the problem of efficient switching of the deflection plates to produce the required scan pattern (initially a TV raster). Historically, this has been the major problem in sequentially presented displays since the earliest beginnings of television research. As will be noted later, this condition would plague the more recent research in a 2-dimensional solid state display medium.

Kaiser Quarterly Progress Report No. 6, dtd May 1956.

The first research on switching was begun in the Spring of 1956. Previously, more conventional high voltage switching tubes were used in the demonstrator and early experimental units.

Kaiser Quarterly Progress Report No. 9, dtd February 1957.

Kaiser Quarterly Progress Report No. 10, dtd May 1957.

Kaiser Quarterly Progress Report No. 12, dtd November 1957.

Of a number of approaches, the beam switching technique of a single tube with multiple cathodes appeared to be the more profitable. Three types were created by Kaiser engineers and evaluated for almost one year. Before a completely satisfactory (for this application) high voltage switching tube had been developed, another technique was thought applicable. A method employing a series of photo-conductors, one to each deflection plate, was used. The photo-conductors (PC) were illuminated by a light source driven by a low power electronic circuit. The change of resistance of the PC material with incident light is the physical circuit change that is responsible for the switching. The recovery time of 2 milliseconds is adequate for the high voltage deflection but not for the low voltage horizontal deflection which still employs conventional tubes.

The incorporation of a tapped delay line for low voltage switching was employed with some success. A series of lumped inductor (L) and shunted capacitance (C) elements make up the line which had a characteristic impedance of 10,000 ohms.

Three configurations of delay line were studied: 1) a distributed parameter, continuously wound line; 2) a lumped-constant bridged-T line; and 3) a similar line with toroidal coil inductors. The important design feature was the incorporation of the deflection plate capacitance as part of the circuit.

Electroluminescent (EL) phosphor materials were investigated as a light source for the PC switches. Study effort was begun to determine if the space and weight saving of the EL-PC combination is worth the increased circuit complexity. This path proved unprofitable due to the meager light output of the EL materials available. Research continues on both the multiple beam switching tube in parallel with the PC-neon effort to provide working components for the delivered flat tubes.

Kaiser Quarterly Progress Report No. 19, dtd August 1959.

Kaiser Quarterly Progress Report No. 21, dtd February 1960.

The third critical area involved the phosphor medium itself. Standard, commercially available phosphors were used on the demonstration tube and are entirely satisfactory for non-transparent applications of the tube as in the horizontal or navigation display tube. The use of the tube for this display was to permit a "desk" type presentation above the operator's lap while leaving ample leg clearance below. The transparent tube for display of information in the windshield area required development of a transparent phosphor. Work on the concept of this vertical tube would not have been continued unless such a phosphor was attainable. Work at the Naval Research Laboratory (NRL) by Egli, Feldman, and O'Hara had created a type of transparent phosphor. With this work in process, the Kaiser effort was directed toward the tube and circuitry problems. Not until late in the tube effort were the problems of deposition and application of these phosphors really apparent. High temperature firing of phosphors required use of special Vycor glass not feasible for tube fabrication. Consequently, a Vycor insert was placed in the transparent tubes. This problem then spurred research at Kaiser and at Servomechanisms Research Laboratory to find a solution to the problem of depositing the phosphor on "soft glass" and thereby eliminating the need for the Vycor insert.

Some success through research at Kaiser improved the meager light output of the transparent phosphor to within 60% of the output available from non-transparent commercial varieties. The success of the tube, however, was collectively greater due to a facet of transparent phosphor phenomena. Because of the transparency of the inactive phosphor and relative opaqueness of the excited elements, ambient light serves to enhance rather than degrade the contrast, thus reversing the characteristics exhibited by standard tubes.

Kaiser experimented with many commercially available phosphors and did achieve some success in improved brightness. However, the severity of the problem at the close of Kaiser contract encouraged the establishment of a display media effort as part of the material research. Results of this endeavor are discussed in the Material and Circuitry Section of this report. It should be noted that the feasibility of the flat tube, both transparent and non-transparent versions, had been established by the research and flight test efforts. The production applicability would depend to a great extent upon the success of the supporting Materials program.

Kaiser scientists contributed a great deal to a number of technologies during the program to develop a practical flat cathode ray tube. New knowledge was obtained in these areas:

- Glass forming
- Glass envelope sealing
- Electron tube technology
- Electron beam dynamics and control
- High voltage switching tubes
- Photoconductor fabrication
- Photoconductor performance
- Delay lines
- Pulse forming networks
- Transparent and non-transparent phosphors
- Electroluminescence

These results in themselves have been successful outputs of the ANIP program and the data are applicable to other scientific regimes.

During the research period of the flat Kaiser-Aiken cathode ray tube from 1955 through 1960 the desires and requirements for a more effective display media device permeated the minds of the research coordinators at the Office of Naval Research, Douglas, and Bell Helicopter. The requirement remained for a flat transparent display medium but the desire was for such a device without the cumbersome evacuated envelope.

Bell Helicopter solicited ideas for such a product via a specification issued in 1958.

Industry response was not extensive. However, those proposals received did highlight a key problem area, coincidentally, that of the flat transparent CRT — how to switch the elements of the display in some sequential manner. Kaiser was again able to set forth a solution due to their knowledge and experience with

the flat tube. A short term contract was let by Bell to permit Kaiser to elaborate on their technique and to prepare a requirements study. To gain additional technical and professional support, Kaiser had Stanford Research Institute subject the proposed program to critical scrutiny. SRI made a critical analysis and delineated the problems that would have to be solved. Within the constraints of solving these problems, they considered the idea feasible. Kaiser added SRI data to some additional study work and reported the total in their final report. A proposal for a continuation of the effort was initiated in August 1959 to establish design and operational requirements and to assemble a feasibility model. The contract for a nine month program was initiated in March 1960. During the latter part of the year, a change in emphasis between the research activities of Douglas and Bell was directed by the Office of Naval Research. Douglas was requested to carry on the Kaiser research under subcontract. A Douglas specification and subsequent Kaiser proposal effected the contract in February 1961. This effort covered a one year period.

Douglas Specification 7816406, dtd April 1961.

"Requirements for a Coincidence-Pulse Scanning System," dtd 15 June 1961.

"Summary Investigation of Solid State Display Devices," dtd 28 July 1961.

"Light Gate Research Report," dtd 10 August 1961.

The reporting procedure was changed from quarterly progress reports to a series of technical reports covering various phases of the research as it progressed. Kaiser began by identifying the system and circuit requirements to achieve proper scanning, using the Aiken coincidence pulse technique. To further support the concept, another report analyzed the history of solid state and related scanning technique, indicating the problems faced by earlier research activities. The Kaiser system was described in terms of its solution to some of the classic problems. One limitation appeared to be that of introducing large amounts of power to the elements of the display during the short dwell time on each element. Even considering 100% efficiency of the phosphor material, the ultimate output would still be inadequate for some high display brightness application. The idea of a light gate was to utilize a separate light source and use the switching technique to some "light gate" such as a Kerr Cell to modulate this source.

The problems of creating a two-dimensional transparent display were similar to those encountered with the flat CRT. A medium, a switching method, and envelope material were required. The desire of Douglas was to approach the creation of the display by means of a thorough requirements analysis. Both Douglas and Kaiser personnel prepared a preliminary analysis to act as guidelines for the investigation. Unavoidably the requirements were initially compromised because so much excellent work had been accomplished under Bell that was oriented specifically to the system Kaiser had proposed at the onset. This method did satisfy the first and second order requirements, so work was to proceed to proof of feasibility.

The essence of the Kaiser technique (another creation of W. Ross Aiken) is best described by this reference from their first proposal: "...consider the display and the switching circuit as a single unit—an inherently broad band transmission line. The resonant properties of the line are utilized by sending pulses along it in proper phase sequence in such a way that pairs of pulses combine to produce the required excitation voltage (for the electroluminescence material) at the appropriate points. Accurate phasing of these pulses... makes sweeping possible. High definition is obtained by the use of sufficiently sharp pulses. Modulation of the light output is achieved by the amplitude modulation of the pulser. The display can utilize 'crossed-grid'

conductors or perhaps continuous conducting faces of the electroluminescence (EL) sandwich. In the first case, the grids may be excited from connections made to a distributed transmission line running along the edge of the display; in the second case, direct excitation of the EL sandwich takes place by the creation of standing waves used to produce the high potential locally . . ."

The first quantitative analysis of the requirement for this pulse scanning technique indicated some severe accuracy and linearity restrictions to enable the coincidence of four pulses (one from each of the four display edges) to add voltages to produce a display. The permissible error in the voltage displacement appears as a function of the number of scanning lines when a raster type display is considered. This value is $1.5 \times 10^{-4}\%$ for a 500-line system. Added to this is the problem of pulse width. The pulse must be narrow enough to prevent a crosstalk to other elements. Again, for a standard TV system, this would require a pulse width of 0.2 nanosec. (10^{-9}) and a pulse bandwidth of 2,310 mc. These represent formidable design problems.

A delay line with a bandwidth of 600 mc that could accommodate pulses with rise times as short as 0.8 ns has been developed. Commercially available pulsers operating at 100pps were used in the test of the "bifilar" line. This is far below the required rate of 13 mc. Emphasis is now shifted to the study of pulse forming networks that will produce pulses at these frequencies with the additional requirement of high amplitude (100 volts or better).

"Kaiser Bar Graph Report 238-A," dtd 12 October 1961.

"Crossed-Field Plotting Board Report 240-A," dtd 6 November 1961.

Several interim applications of the technology developed to date were suggested by Kaiser, including a simple one by one hundred element "bar graph" indicator that could be used for power or status displays. Another was a 100×100 matrix plotting board for low resolution displays.

DATA PROCESSING

Reference to the man-machine pictogram indicates that data processing is the operation that has sensory information as inputs and provides two categories of outputs: pilot display and auto-control machine functions. This area can be defined more precisely as: all operations within the energy state and communication media of the machine portion of the total system. For efficient operation, it was originally hypothesized that all required functional manipulations of data should be accomplished in one energy form and at as low a power level as possible to conserve energy. The companion role of the sensors, control and display media is to convert or transduce this energy state for observation or to affect the external environment. Equally important, this simplified approach enabled the coordinator to beter communicate the boundaries of research to the subcontractor participants in the program. An additional main advantage was realized as system studies progressed when it became apparent that unwanted redundancy and complication could be eliminated from actual data processing equipments using this concept. The origination and initial work on this central control computer concept, which exchanges redundant physical mechanisms for time-shared memory, was that of Floyd G. Steele, then with Litton Industries.

Throughout the following summary of data processing activities within the fixed-wing portion of ANIP research it can be noted that realization of this objective involved a number of interim stages. The most prominent of these were the analog function generators designed to create the visual displays while the majority of other functions were handled by a central digital data processor. This "crutch" still remains, but to a lesser degree since the advent of the digital processing of the contact analog display in the last two years of the program.

The systems analysis work by Douglas and system feasibility studies by early subcontractors had determined the need for improved means of handling data. The concept of an integrated display and the establishment of the information requirements for all-weather flight created the requirement for the processing of enormous quantities of data in real time.

Known equipments and techniques were several orders of magnitude below these new performance requirements. It was also evident in the summer of 1954 that means of implementing this preliminary human factors display requirements would have to be included in the data processing studies contemplated. It was desired that the visual cues that had been tabulated be generated in the form of an electronic display. The electronics staff at Kaiser, while working on the flat tube, were aware of this need and the additional requirement to place the display on the flat transparent display medium. An approach was suggested to Douglas that could work in lieu of a long term research effort at that time. By December of that year, when the second flat tube contract was initiated, work to include an investigation of the proposed scheme was also started. No plans were made to implement the techniques beyond a laboratory feasibility model. It was anticipated that the computer long range research program could absorb this function generation in the central computer.

Data Processing, 1954-1957

Douglas Specification 7540324.

Subcontract DAC 55-302 (Dec. 7, 1954) and supplemental agreements Nos. 1 thru 9.

The first specification for research into new computer technology established both a long range and an interim program. The analysis was to provide the design of a single central computer that could accomplish the necessary computations for navigation, cruise control, fire control and flight control for a single place all-weather aircraft. The evaluation of 31 proposals submitted by industry, based upon the quality of the proposal and background of their available personnel, was conducted by a joint Douglas-ONR group

with the result that Litton Industries was selected as subcontractor. Reliability, simplicity of design, light weight and small size were of paramount importance as were the objectives that this would be an important link in an optimum man-machine system. Litton proposed this specific approach:

1. Establish long range computer requirements.
2. Conduct a computer survey of the latest advances in the art.
3. Establish specific design requirements for an interim computer.
4. Fabricate a breadboard version of an interim computer subsystem for feasibility demonstration.

In order that the data processing effort be more clearly summarized, the presentation is in two sections covered by the periods of the two specifications issued for the computer work at Litton, Inc. These are — 1954 thru 1957, and 1958 thru 1962. Work is generally grouped as follows:

- Survey of the computer art
- Systems studies
- Computer component and subsystem research and development
- Computer functional specification, design and development
- Display generation

Work by other subcontractors than Litton in this field is also included. They are Kaiser, General Electric, Avion, Dodco and Amelco. A subject index of the major content of the Litton reports is given in Table II.

Survey of the Computer Art — Litton, 1954–1957

Survey of the state of the art was a continuing operation throughout the Litton program.

Preliminary survey data of computer state-of-the-art was compiled in chart form and related to the anticipated mission. Qualitative results showed major digital field effort in 1955 was directed toward computing components rather than input-output conversion which would be useful to the program.

An extensive state-of-the-art survey was compiled in 1957 for airborne control computers. Also future trends and needs were formulated. Issue of this report essentially completed the major work outlined in the first Douglas Specification 7540324.

System Studies — Litton, 1954–1957

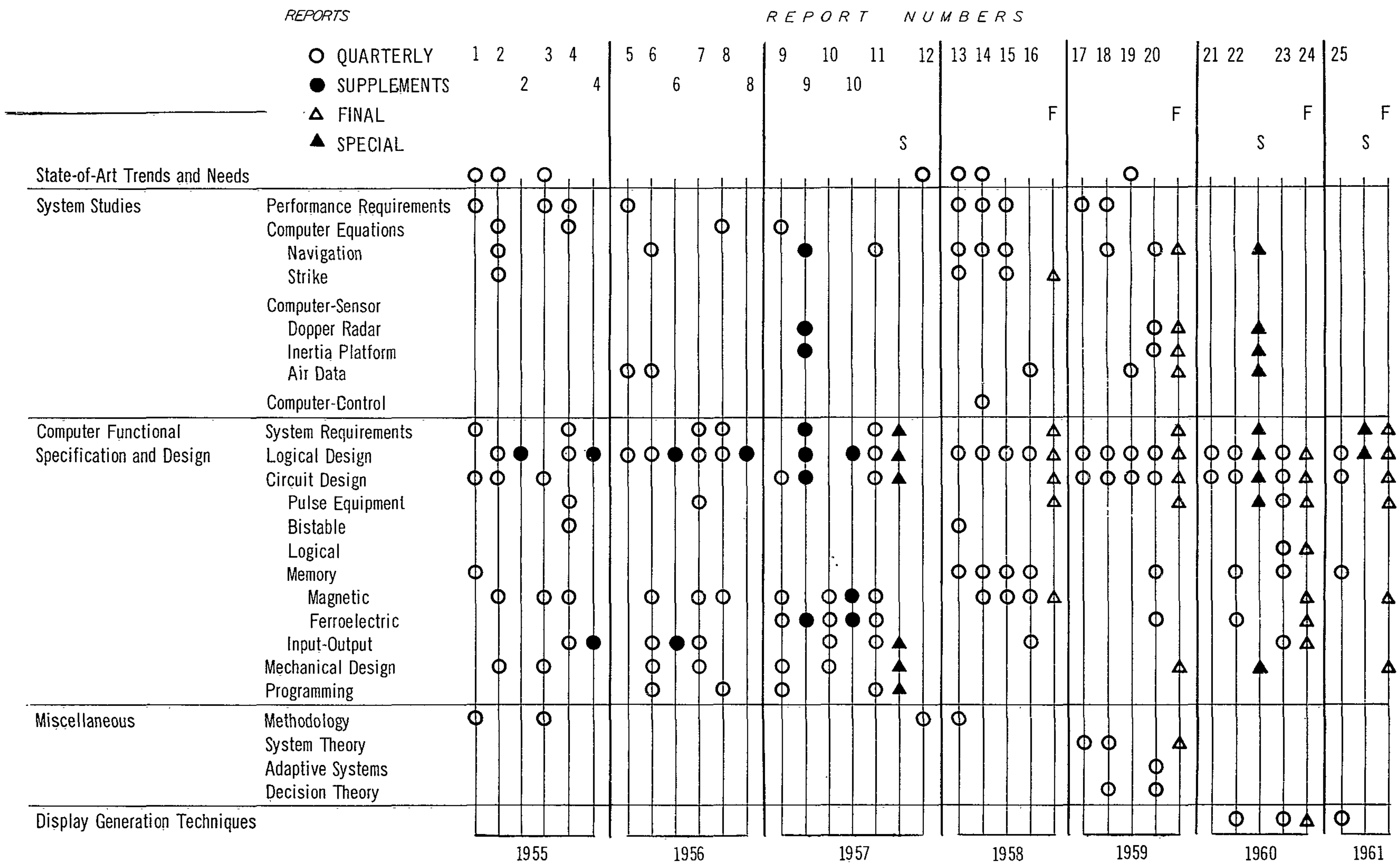
Systems studies were concerned with definition of the requirements for the central computer and the reduction of these to mathematical terms for solution by a computer.

1st Litton Quarterly Progress Report, dtd 24 March 1955.

2nd Litton Quarterly Progress Report, dtd 7 June 1955.

3rd Litton Quarterly Progress Report, dtd 15 October 1955.

12th Litton Quarterly Progress Report, dtd 15 December 1957.


REPORTS
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State-of-Art Trends and Needs
System Studies
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Computer-Sensor
Dopper Radar
Inertia Platform
Air Data
Computer-Control
Computer Functional Specification and Design
System Requirements
Logical Design
Circuit Design
Pulse Equipment
Bistable
Logical
Memory
Magnetic
Ferroelectric
Input-Output
Mechanical Design
Programming
Miscellaneous
Methodology
System Theory
Adaptive Systems
Decision Theory
Display Generation Techniques
1955
1956
1957
1958
1959
1960
1961

1st Litton Quarterly Progress Report, dtd 24 March 1955.

The first work in 1955 outlined the relationship of the central computer to the overall system and set forth the tasks necessary to be accomplished such as (1) coordinate with Douglas in definition of the tactical requirements of the piloted aircraft system, (2) define, evaluate and set up the optimum airframe and weapon system, (3) establish output requirements of the computer, (4) examine basic parameters concerned with conditions within the aircraft, environment outside of the aircraft, measurements of velocity, position, and attitude of the aircraft, and measurement describing the position of the targets, (5) establish probable accuracies to which quantities can be predicted from ground level and transmitted to or preset in the aircraft, (6) formulate mathematical expressions for the particular output to be achieved, (7) determine after survey of the art the most appropriate computational techniques, (8) analyze computer requirements to solve equations, and (9) detail block diagram and system synthesis using time-sharing and multiplexing. Work areas included (1) systems studies, (2) coordination with feasibility study groups, (3) survey of the computer art, (4) component research and development, (5) specialized component research, (6) subsystem development.

2nd Litton Quarterly Progress Report, dtd 7 June 1955.

Early in 1955, overall system work for the long range or Advanced Central Control Computer (ACCC) concerned itself with the navigation and strike phases of flight and analyses were made to minimize the amount of equipment involved.

3rd Litton Quarterly Progress Report, dtd 15 October 1955.
4th Litton Quarterly Progress Report, dtd 15 January 1956.
5th Litton Quarterly Progress Report, dtd 15 April 1956.
6th Litton Quarterly Progress Report, dtd 7 August 1956.
8th Litton Quarterly Progress Report, dtd 15 December 1956.
12th Litton Quarterly Progress Report, dtd 15 December 1957.

An increase in scope of the Litton program was initiated during the summer of 1955 which required a model of an Interim Central Control Computer (ICCC) for flight test in a T2V aircraft compatible with interim display equipment rather than a simple computing subsystem breadboard. These displays were a vertical display, a horizontal display and indicators. Necessary outputs from the computer were worked out in cooperation with Douglas and Kaiser for optimum climb velocity, maximum range, present range, present endurance, maximum endurance, present position, ground speed and track. Speed capabilities limited the computer's role to providing the relatively slow changing variables in the vertical display, such as ground speed.

In 1956 navigational error analyses were made, and from these and other system work on air data appropriate equations were derived, based on the Douglas F5D as a typical vehicle. Later, a preliminary evaluation study on a Central Control Computer for a Douglas A3D test aircraft was begun. The A3D, a three-man aircraft, lent itself to easier flight test evaluation than the single-place F5D. This second flight test program did not materialize, so further work in this area was not pursued.

During 1957, analysis of system design philosophies evolved an orderly design methodology starting with mission requirements and ending with detail material requirements for the resultant computer system. This formalization was also applicable to subsystem interdependence and system management problems, and led to the general systems theory work in 1958.

9th Litton Quarterly Progress Report, dtd 15 March 1957.
Supplement to 9th Litton Quarterly Progress Report, dtd 15 March 1957.

Synthesis of equations for inertial navigation and fire control was continued in 1957 and requirements for sensors and actuators explored for the ACCC.

Computer Component and Subsystem Research and Development—Litton 1954-1957

11th Litton Quarterly Progress Report, dtd 15 September 1957.

Litton Quarterly Progress Reports 1 through 4, dtd 24 March 1955 to 15 January 1956.

Component development proceeded in three categories during 1955 in preparation of "building blocks" for the subsystem breadboard. These were: (1) transistor circuitry, (2) magnetic commutation, and (3) magnetic rigid and flexible disc memories. Transistor circuitry appeared so promising that it was to be used in the breadboard models.

Supplement to 2nd Litton Quarterly Progress Report, dtd 15 June 1955.

Supplement to 3rd Litton Quarterly Progress Report, dtd 15 January 1956.

Several computational techniques applicable to the program and proprietary to Litton were published in a supplement to the 2nd and 4th quarterly reports. This covered the theory of the "Di-Function," "Triad" and "Neuron." The Di-Function connotes a function which has two values, +1 and -1. Pulse sequences of +1 and -1 are used to represent fractional numbers. They are capable of being added or subtracted, multiplied or divided. Di-Function multiplication and division is accomplished by means of a "triad" computing device consisting of three registers and a number of adders and subtractors. The "neuron" is an analog-to-digital converter element which, upon interrogation, replies with a pulse in a time interval proportional to the analog parameters set into the device.

Supplement to 4th Litton Quarterly Progress Report, dtd 15 January 1956.

Work continued at an accelerated pace in late 1955 and 1956 for the flight test computer. Component development included head and drum development, memory read amplifier, momory record amplifier, clock signal generator, flip-flop, analog-to-digital conversion and generation of true time.

Significant component developments during 1955 included contact read and write heads, rigid disc memory, a single transistor flip-flop and an analog-to-digital converter. An example of subminiature packaging technique was a dual flip-flop unit having a volume of three cubic inches. This compares with flip-flops developed in conjunction with Varo, later in the program, of approximately 1% this volume.

Litton Quarterly Progress Reports 5 through 8, dtd 15 April 1956 to 15 December 1956.

Components for the Interim Central Control Computer (ICCC) utilized etched circuitry fabrication techniques. Other components requiring development for the ICCC were a mechanical commutator, a precision frequency power source and d-c power supply.

Supplement to 6th Litton Quarterly Progress Report, dtd 7 August 1956.

Supplement to 8th Litton Quarterly Progress Report, dtd 15 December 1956.

During 1956 analog to Di-function conversion techniques, variable frequency to Di-function conversion, and voltage to Di-function conversion were developed. Details of the Di-function generation method were defined and stability of solution was studied to indicate what disturbances would be introduced into a control system. Methods were explored to speed up the Triad method of multiplication, which was inherently slow. Logical design was solidified to effect the advantages of a flexible machine capable of Triad solution plus all the abilities of a digital differential analyzer. All improvements thus attained were applied to the ICCC design.

Litton Quarterly Progress Reports 9 through 11, dtd 15 March 1957 to 15 September 1957.

The Advanced Central Computer program was continued at an accelerated pace during 1957 as the ICCC program tapered off. Even so, the effort was at about ½ that necessary to bring a prototype ACCC into being by 1958 as originally proposed. Emphasis was on the development of more advanced techniques for the type

Supplement to 9th Litton Quarterly Progress Report, dtd 15 March 1957.

Supplement to 10th Litton Quarterly Progress Report, dtd 15 June 1957.

11th Litton Quarterly Progress Report, dtd 15 September 1957.

of subsystems contemplated for use in the ICCC. Study and experiments on advanced techniques and components for use in integrated aircraft instrumentations and control were made. Considerable effort was expended toward developing ceramic formulating principles and evolving compatible electronic circuitry for doped barium titanate ferroelectric memory for stepping registers. Objective specifications for a stepping strip memory were formalized. A stepping strip memory is analogous to a channel on a magnetic drum memory with the exception that there are no moving parts. Information is made to move from one memory location to a next location electronically. Also it offers potential of configuring stepping strips to branch or combine information to perform logic.

Computer Functional Specification, Design and Development—Litton, 1954-1957

Relationship of a central computer to the overall system and tasks including the computer functional specification and design were outlined in 1955 (see page 42). Two possible subsystems for early breadboarding were studied in 1955 and the one which concentrated most heavily upon input-output conversion was pursued. Work continued on this breadboard system until mid-1956 when it was demonstrated. As a result of this experiment, improvements in head and drum design were evolved.

Litton Quarterly Progress Reports 4 through 8, dtd 15 January 1956 to 15 December 1956.

During 1956, work on the ICCC final design and fabrication was completed. Detail logical design, gating networks, memory structure and input-output circuitry were solidified and detailed programming was started.

7th Litton Quarterly Progress Report "A Progress Report on the Design of an Airborne Central Computer for the Integrated Instrumentation Program," dtd 1 October 1956.

The seventh quarterly progress report outlines the features of the Interim Central Computer (ICCC). The packaging was accomplished in 5/8 cubic foot including input-output conversion equipment and power supply. This was about 1/3 the size of the equipment then available to accomplish an equivalent job. Specifically the ICCC performed the following functions: (1) computed true air speed, ground speed, Mach number and altitude, (2) computed present position, (3) automatically accepted wind correction from TACAN and modified assumed wind velocity to make up for the error, (4) computed range, endurance, optimum speed, altitude, and climb velocity, (5) computed estimated time of arrival, (6) computed ground speed, altitude, and flight path angle for the special vertical display in the T2V flight test aircraft.

Salient features of the computer included:

1. Computing capacity: Equivalent to about 250 analog operational amplifiers. Both arithmetic and integration operations were performed.

   integration operations were performed.

2. Computing accuracy: Flexible, number of bits in each computer word is at option of programmer.
3. Maximum inputs: 30 digital or analog.
4. Analog input conversion accuracy: 0.1%.

5. Maximum number of outputs: 30, as d-c voltage.
6. Analog output conversion accuracy: 1%, using a closed loop.
7. Solid state components: Silicon transistors and diodes.
8. Memory: Magnetic drum with floating heads; bits spacing 200/inch.

Supplement to 9th Litton Quarterly Progress Report, dtd 15 March 1957.

Although the hardware was assembled and the computer physically available for inspection at a presentation to ONR in October 1956, considerable work remained to be done including programming, test equipment development and checkout of the computer. Improvements in speed and reliability under adverse power supply conditions were initiated and reported.

9th Litton Quarterly Progress Report, dtd 15 March 1957.

11th Litton Quarterly Progress Report, dtd 15 September 1957.

S(1) Per Table II "Preliminary Operations and Maintenance Instructions, Interim Central Control Computer for T2V-1 Aircraft," dtd 1 November 1957.

Programming for the ICCC continued early in 1957. Program fill equipment, an input simulator, output indicator and other test equipment was developed to enter the program into the computer. The computer had been operated about 550 hours by June 1, during which time a large number of equations were successfully programmed into the machine. Several problems arose, delaying the final delivery of the unit. Inconsistency in the first generation silicon transistors made some circuitry redesign necessary. Mechanical problems with the internal magnetic drum drive motor required a redesign. Distortion of the cantilever read and write heads support also limited the allowable operating temperature range. With this limitation the unit was delivered in September 1957 for final checkout and integration with the vertical and horizontal display systems for flight test in the T2V airplane. Checkout of the computer was completed satisfactorily in a ground laboratory setup. However, due to the unreliability of the breadboard vertical and horizontal display equipment, the flight demonstration of all the computer features was not accomplished. Redesigning the interim vertical display equipment for a more rigorous flight test had not been deemed advisable in anticipation of an all-electron generator, then in development at Kaiser.

There were minor carry-ons, however, with the Interim Central Control Computer. Programming changes to facilitate the flight test were made in 1958 and redesign of the magnetic drum and heads and motor was accomplished in 1960. Slightly increased bit spacing on the memory drum alleviated the temperature distortion problem. The computer was to be utilized in a ground laboratory system (RV-1B) similar to the T2V flight test system but with improved displays. However, attempts to reactivate the computer in 1960 were abandoned because unhermetically sealed silicon transistors failed at an accelerated rate.

Display Generation – Kaiser, 1954-1957

Douglas Specification 7557413. Subcontract Douglas Aircraft Company 55-400.

1st Kaiser Quarterly Progress Report, dtd 28 February 1955.

Early in 1955, Kaiser developed the mathematical expressions for the basic visual cues for the vertical display in terms amenable to electronic generation and some simple circuits were built whose outputs were compatible with the flat cathode ray tube (CRT). Implementation of these equations with the geometric fidelity of the real world would not occur for six years, however.

2nd Kaiser Quarterly Progress Report, dtd 31 May 1955.

A number of alternative schemes for the generation of a basic grid pattern originally shown for the contact analog were studied throughout 1955. No completely electronic system appeared to be feasible then. By the time of the ANIP symposium in September, the interim design was fixed to utilize a spherical ball memory with the grid lines etched in the surface. A small rectangular section of the sphere was illuminated by a spot of light from a flying spot scanner. A standard television sweep was applied to the cathode ray tube. The light reflected from the white lines and dark surface of the ball modulated a set of photomultiplier tubes whose signal output would be the television video. This portion of the system created a grid display on the CRT, oriented in space in angular agreement with the spherical ball memory. The ball was positioned by servomechanisms connected to attitude sensors. Rotational but not translational fidelity was obtained.

The major problem was in giving a sense of motion to this static display. A large number of circuits were required to shift and distort the television raster between frames to give the illusion of motion.

The significance of the solidification of the design was the announcement at the 1955 symposium that a flight test program was to begin with the flat tube, a central digital computer, and this generator as the key equipment. Kaiser continued to make improvements but they were subservient to the packaging of their laboratory "breadboard" for installation in the T2V aircraft for flight test. This and other laboratory type equipment limited the flight test program to essentially a qualitative test, as poor reliability did not allow extensive flight testing. An additional model was fabricated for use in the Douglas simulator laboratory and also as a possible spare for the aircraft.

The continuing insistence on geometric and motion fidelity was based on the consideration that a replication of real world visual cues must be consistent or the concept of an instrument display analogous to contact flight would not be realized.

Data Processing, 1958-1962

Late in 1957, the Army-Navy Instrumentation Program Materials and Techniques Joint Working Group was formed consisting of Douglas Aircraft, Litton Industries, Servomechanisms, Inc. (SMI), and Varo Mfg. This provided a balanced team for data processing research with Douglas providing system requirements and coordination; Litton computer, component and circuit requirements, experimental evaluation, logical design and packaging; SMI providing material research; and Varo, circuitry research and development. SMI started experiments at this time to produce a thin magnetic film stepping strip.

Douglas Specification 7672188. Subcontract Douglas Aircraft Company 55-302, Supplemental Agreement 10 through 14, dtd 15 June 1957 to 16 June 1958.

In cooperation with Litton, Douglas defined and issued a second specification on an Advanced Central Computer which defined the requirements for research leading toward a computer capable of central and display functions for advanced naval interception, fighter or attack aircraft. Computer functions included auto control, power plant control, armament control, auxiliary functions, and display functions for the contact analog and flight path in the vertical display and the aircraft situation in the horizontal display.

Studies in computer and systems logic were authorized with effort to stress computer organizations that would utilize stepping strips. Also studies and evaluation concerned with computer elements were to include functional and detail specifications and experimental evaluations of such things as stepping strips, circuitry, gating techniques, input-output techniques and digital servos.

Computer State-of-the-Art, 1958-1962

Litton Final Engineering Report for 1958.

Survey of the state of the art, a continuing endeavor throughout the program, was reported upon sporadically. A survey reported in 1958 consisted only of ANIP work and included (1) the RV-2 Central Computer logical design, (2) the Hybrid fast loop system, (3) COBS and CAPS electronic stepping circuits, (4) magnetic frequency multiplier, and (5) magnetostrictive delay line memory.

13th Litton Quaterly Progress Report, dtd 16 March 1958.

15th Litton Quartorly Progress Report, dtd 15 September 1958.

An evaluation of contemporary work on the application of magnetic cores in digital computers was documented including coincident current, linear select methods and a method dependent on the viscosity of the magnetic domain wall. Also the "Twister," a new magnetic storage element, was described.

16th Litton Quarterly Progress Report, dtd 16 December 1958.

19th Litton Quarterly Progress Report, dtd 15 October 1959.

A survey of contemporary autopilots was documented. An extensive state-of-the-art survey on air data computation in extended range up to Mach 3.0 and 150,000 feet was made. A cruise control study based on the A2F aircraft was also made for possible application to the RV-2

System Studies — Litton, 1958-1959

20th Litton Quarterly Progress Report, dtd 15 January 1960.

13th Litton Quarterly Progress Report, dtd 16 March 1958.

Early in 1958, system performance aims were reviewed and environment established for the RV-2, the second research system. Some of the long term needs were believed to be in the areas of general system philosophy, information compression, statistical logics and chemical cybernetic models. An approach to the study of hybrid systems was described.

17th Litton Quarterly Progress Report, dtd 15 April 1959.

18th Litton Quarterly Progress Report, dtd 15 July 1959.

20th Litton Quarterly Progress Report, dtd 15 January 1960.

Efforts were applied in generalized system and decision theory in attempting to derive a useful theory less general than one appropriate for an all-purpose system but more general than one appropriate for one specific system. Forging descriptive tools to bring the human into system analysis was one of the aims of this work. Some decision theory elements were experimentally built and demonstrated. Work on adaptive systems was also initiated. Some experiments utilizing electrical pulse trains to control human muscular activity and muscular potentials to control an electric motor were made and demonstrated.

Final Engineering Progress Report for 1959.

Late in 1958 and 1959 cooperative effort with Douglas accomplished preliminary definition of the RV-2 system requirements for the vertical and horizontal display.

Litton Quarterly Progress Reports 13 through 20, dtd 16 March 1958 through 15 January 1960.

Hybrid navigation studies for the RV-2 system utilized combination of position, velocity and acceleration inputs from such sources as celestial trackers, Doppler radar, inertial platforms and air data. Fuel management, air data computation and engine control were also studied. Definition of a six-degree-of-freedom air-

craft dynamic simulation for the RV-2 simulator was also generated.

Litton Final Engineering Report for 1958.

A minor effort on reliability of certain simple redundant circuits showed a group of four resistors being approximately 100 times more reliable than a single resistor. This demonstrated the need for redundancy at the simpler element stages of a system rather than at or near the final product level.

Litton Final Engineering Report for 1958.

Nuclear weapon control work described effects and accuracy requirements and trajectory equations for nuclear weapons.

System Studies – Dodco, 1958-1960

The fundamental purposes of applied research include not only establishment of the feasibility of a given task, but also determination of the "best" means for its accomplishment. This is especially critical where system non-linearities exist. Aerodynamic compressibility, for example, introduces a disproportionate increase in drag with speed near the speed of sound and therefore attainment of "best time to altitude" becomes a sensitive endeavor.

Previous work by D. O. Dommasch of Dodco for the Air Force had developed techniques based on variational calculus methods to optimize aircraft performance in range, climb and maneuvers. Application of these methods in studies for ANIP started in early 1958 by Dodco Inc. and continued to mid-1960. These studies, initiated by Douglas Specification 7672750, were concerned with the data acquisition and data handling requirements for advanced vehicle control. Concurrently, at the direction of the ONR Scientific Officer, an effort was launched to describe proposed gravitic and unified field theories in mathematical terms.

Douglas Specification 7672750.

The program was in 6 phases.

Phase I consisted of an examination to simplify the programming of the Litton Interim Central Control Computer developed for ANIP flight test in a T2V aircraft. Possibility of utilizing this computer to implement one of the dynamic performance programs such as required for minimum time maneuvers was anticipated. It was concluded that more precise means of optimizing the existing ICCC programming would not noticeably improve the subsonic performance. A more flexible organization of the computer that would allow easier reprogramming was thought desirable, however.

Phase II consisted of the data handling requirements to establish an airborne computer system capable of optimum performance at speeds up to Mach 4 and altitudes of 150,000 ft. Minimum time turn programming at constant load factor provided a simplification of programming for turning maneuvers. It was determined feasible for a small internal computer. However, programming for minimum time to climb or maximum range

would require ground computer support by data link or preprogramming the anticipated atmospheric conditions for the particular flight and then utilizing an internal computer with inputs based on such aircraft parameters as weight, altitude and Mach number.

The combined use of aerodynamic and reaction controls for this altitude range makes the use of an optimum adaptive system for internal energy conservation very attractive.

Use of the same techniques for optimization can be utilized in the design of the vehicle control system itself. Also, proper "feel" characteristics can be achieved when unstable configurations are involved.

DODCO TR No. 61 "A Brief Review of the State-of-Art of Optimum Performance Determination," dtd 16 July 1959.

Use of these dynamic performance methods finds potential advantage in the operations of high performance vehicles in terms of:

- Marked increase in operating envelope
- Reduced time to climb, including altitudes in excess of the static ceiling and
- Controlled maneuvers at less than one "G" acceleration

DODCO Final Report for Douglas Aircraft Contract DAC 58-605, Specification 7672750, Phases 1, 2, 3, & 4 dtd 5 May 1955.

To take advantage of these increased capabilities, new tactics are required. Therefore, a specific optimum (minimum time to climb) program for a Navy operational F4U aircraft was defined. However, due to the precise programming of Mach number and acceleration that was required for a pilot to follow and the limitations of contemporary instrumentation, a flight test was not believed to be meaningful and so not made.

Phase III, V, VI were concerned with performance programming and data handling requirements for orbital vehicles and were supported in conjunction with the Air Force. Navigation problems were considered, including such things as the rotation of the atmosphere and gravitic perturbations.

Winged re-entry vehicles with adaptive temperature sensing control showed advantages over ballistic re-entry configurations. Combined aerodynamic and rocket vehicle systems with the aerodynamic lifting vehicle utilized for launch of the rocket vehicle showed many advantages. Sensor and control criteria for various mission segments were developed and effects of tolerances at initiation of re-entry were examined.

DODCO Final Report For Douglas Aircraft Contract DAC 58-605, Specification 7672750, Phases 1 through 6, dtd 30 June 1960.

Phase IV was a study to mathematically describe the gravitic and Unified Field Theories of D. Shearer of M.G.M. which had come to the attention of Office of Naval Research. The potential gain of knowledge leading toward possible gravitic shields warranted this effort. However, attempts to formulate a satisfactory mathematical model by Dodco, after several conferences with Mr. Shearer, were unsuccessful. Experimental work at Douglas which attempted to replicate key experiments claimed to have been accomplished by Mr. Shearer were also unsuccessful. This work stimulated investigation of another unifying theory (proposed by Mr. Dommasch of Dodco) employing the concept of a medium through which light propagates. It is called REF (radiant energy fluid) theory and is claimed to be consistent with the results of experimental

investigations intended to verify Einstein's special theory of relativity. Key experiments which may serve to establish validity of the hypothesis were defined, but, due to funding restriction, no further action was taken.

DODCO TR No. 69 "The Complete Development of Dynamic Performance Analysis Techniques Applicable to the ANIP Program," dtd November 1959.

Results of Dodco work were reported in eight quarterly progress reports and two final reports. The final reports include a complete bibliography of Dodco work on ANIP and other projects. Dodco TR61 gives a review of the state of the art as given at the 1959 Symposium in Dallas (and is also included in the symposium report). Dodco TR69 (declassified) gives a complete treatise on the methods of "dynamic performance analysis."

System Studies – Amelco, 1961-1962

Work in the stepping strip computer was proceeding reasonably well in late 1960. A point was reached in the research cycle similar to that of 1957. The basic feasibility of the ICCC concept seemed assured, so additional effort was placed on advanced ideas. Similarly, in 1960 the objective was to look ahead. The emphasis at Litton on research of this nature was momentarily interrupted when members of their staff left to form Amelco, Inc. It was not too long after that that an interesting and far-reaching idea for future data processing systems came to Douglas as an unsolicited proposal from Amelco. ONR concurred that a small study contract was warranted to explore this unique approach. A two-month study was initiated in which Amelco presented data in the following areas.

Amelco Report No. 1 "Data Processing," dtd June 1961.

- Information aspects of data processing systems
- Information aspects of the total man-machine system
- Criteria for evaluating various data processing systems
- New technology from which future systems might evolve

Amelco first described the general class of data processing devices by means of their common denominator, information, data then being defined as information plus noise. Information has the characteristic of both spatial and time dependence. Problems associated with data processing generally have to do with changing the spatial and/or temporal location of the information without increasing the associated noise. This creates the possibility of a law of data processing that states: "within any isolated data processing system, data can neither be created nor destroyed." By both a conceptual and mathematical relationship to a similar familiar concept that energy can neither be created nor destroyed within any closed system, Amelco suggested an equivalence of information and energy. Or, more precisely, that information is a measure of the energy distribution within a system. This expression permits analysis of data processing networks by considerations of energy conversion and transmission.

The informational aspects of the total system were discussed in terms of the human requirements for machine aid. It was recognized that man conceives and constructs the machine to: 1) extend his sensory ability to extract information from his environment; and, 2) increase his capability to effect some change in this environment. With this objective in mind, the role of the data processor becomes one of arranging the information from the energy form of the environment into a state acceptable to the human sensors and the equivalent for the output to the environment. A secondary objective of such a system would be to process the required information with no degradation or addition of noise and with a negligible loss of system energy.

The comparison of data processing systems for the purpose of observing trends and for predicting potential areas for future growth requires a method of equating or normalizing broad classes of devices in this category. A number of contemporary examples of computer types, both whole number general purpose (GP) and incremental (DDA), were tabulated as to their characteristics. Amelco suggested that a key normalizing value would be channel capacity in bits per second. Each example was examined by plotting the normalized volume (cubic ft/bit per second). Military and commercial machines were plotted separately so that trends in each area could be observed. The influences of technological advances such as the transistor were apparent in these charts. Volume and cost are only two of the innumerable variables that could have been considered. An "N" dimensional set of equations could be employed to further define the limits of the computer art. With new computer requirements stated in terms of both these variables and the normalizing function, it would be possible to determine whether or not a class of data processing systems existed which could meet these requirements. If not, it could highlight what research should be performed to extend the class to include these new requirements. This tool and its application were not carried further by Amelco. Mechanization of the scheme is left for the developmental users of data processing systems to exploit.

Amelco Report No. 2 "Data Processing," dtd January 1962.

In the second phase of study, Amelco explored a type of system not previously considered in great detail due to the lack of formal organization of material in the field. This class of data processing system is termed "non-numerical" and is one in which a particular pattern of input data is arranged in space and time to produce a sequence of output data in a similar space-time regime without the intermediate requirement of an established numerical or tabulated process common to existing systems. Man has constructed historically a scheme of numbers and numerical relationships so as to communicate and implement his desires. This is accomplished even though the means with which the human system processes the data is not believed to be numerical. Capitalizing upon the existing information that the natural sciences have gleaned as to performance of biological systems, Amelco has conceived of a system having similar properties that would advance the state of the computer art.

A non-numerical system is essentially an adaptive system. A technique was suggested for synthesis of a basic "non-numerical" element into the networks necessary for an actual system. It is this network synthesis that would permit such systems to be constructed and is the detail formality that prevented application of "non-numerical" concepts in the past.

A great deal of research is required beyond this initial expression of the concept. The prime program was concluded before this area could be explored further.

Computer Component and Subsystem Research and Development—Litton, 1958-1962

Litton Quarterly Progress Reports 13 through 16, dtd 16 March 1958 through 16 December 1958.

In 1958 several means to accomplish the movement of information within a memory were studied theoretically and experimentally. Among the electronic means was an oscillator circuit called COBS (Carrier Operated Bistable) circuit capable of 2 stable operating frequencies by voltage bias control of the capacitance of a diode. An inductor was required, making it difficult to fabricate by thin film deposition techniques, and coupling the circuits for stepping of information was not successful. A two-transistor CAPS (Capacitor Storage) circuit was simpler in that only resistors, capacitors and transistors were required. Varo attempted to make a twelve-bit mocrocircuit of CAPS using conventional transistors and thin film deposition for the passive elements, but no satisfactory operation was obtained during 1958. Magnetic means of stepping considered were cores, tapes with perforations for windings. The concept of using individual magnetic domains within a continuous film evolved. Transfer of information along the strip depends on the influence of the neighboring domains and upon electrical (clocking) signals applied to conductors passing over the film strip. This method was pursued by Servomechanisms, Inc. (SMI) and this principle was demonstrated in September 1958. Viewing the magnetic domains with polarized light facilitated the observance of information transfer from one end of a strip to another. Optimism ran high in the hope that degradation of information and elimination of noise in a long or recycling memory would be minor problems. The optimism was not entirely justified. Although the degradation problem was solved by December 1958, it took until May 1961 before short linear stepping strips were continuously operable.

Other Litton efforts in 1958 included:

Litton Quarterly Progress Reports 13 through 14, dtd 16 March 1958 through 16 June 1958.

1. The conception and elaboration of a scheme called the Hybrid Fast Loop, which would allow part of a computer to operate at higher speed and lower accuracy than the main part of the computer.

Litton Final Engineering Report for 1958.
Litton Quarterly Progress Report 23 through 24, dtd 1 November 1960 through 15 February 1961.

2. The experimental testing of a magnetic frequency multiplier intended to supply stepping clock power. The unit performed, but at low efficiency. Sporadic work on this idea continued until 1961 when further theoretical developments made it clear that low efficiencies were inherent in this type of device.

Litton 1961 Final Engineering Progress Report.

3. The development of a magnetostrictive delay line memory with readout independent of the pattern of information stored on the line.

Litton Quarterly Progress Reports 14 through 20, dtd 16 June 1958 through 15 January 1960.

4. The development of a linear select core memory capable of withstanding military temperature environments.

Litton component research in 1959 included:

1. Electronic circuit specifications and breadboard design for read and write amplifiers and flip-flops to be made into equivalent microcircuits by Varo.
2. Computer environmental test requirements, detail packaging and preliminary assembly packaging design and mockups.
3. Work on a design of an improved all-magnetic frequency multiplier to be used as the clock drive for the stepping strips.

Litton Final Engineering Progress Report for 1959.

Research was continued into the semiconducting properties of ceramic materials, and laboratory tests conducted to determine the feasibility of using such materials for diodes and transistors.

Litton Quarterly Progress Report 20, dtd 15 January 1960. Design of 4096 Word Microsecond Film Store, J.B. James International, Computers and Tabulators, Ltd. Reported at 1962 WESCON, Los Angeles, Calif., 21-22 August 1962.

In 1960, a specification of a random access memory utilizing stepping strips as static memory only, was synthesized. No experimental work was done on this memory, inasmuch as it was thought to be a developmental rather than a research item. This proved to be true, as a random access memory using continuous thin film was reported by the British in the summer of 1962.

Litton Quarterly Progress Reports 22 through 24, dtd 1 August 1960 to 15 February 1961.

SMI efforts in 1960 to make the stepping strip follow around a corner necessary for the long recirculating strips were unsuccessful, so effort was slowed on the RV-2 research application in favor of a study of advanced computer techniques during the last half of 1960. Specifically, microwave computing was theoretically and experimentally studied and capabilities in the 400 megacycle range were determined. Also a new concept of utilizing a continuous resistive film and active elements introduced thereon to effect a flip-flop or amplifying action were investigated. These circuits were called "slab circuits" and are amenable to vacuum deposition thin film production. Study of barium titanate ferroelectric material was made and a 16-bit random access memory breadboard was demonstrated to show large output signals, simple support circuitry and high resistance to nuclear radiation.

Computer Functional Specification, Design and Development—Litton, 1958-1962

Litton Final Engineering Report for 1958. Litton Quarterly Progress Reports 17 through 19, dtd 15 April 1959 to 15 October 1959.

After the principle of a stepping strip had been demonstrated in the fall of 1958 by SMI, the potential for branching and combining strips to perform logical functions was sensed by Litton and a logical design for a digital differential analyzer computer utilizing this yet-to-be-obtained capability was designed. The mechanization of the basic part of the computer is different in that all information processing and communication is in the form of magnetic fields rather than current and voltage devices. Pulses of current are required only to drive continuous windings in conjunction with the magnetic stepping strips. This is the function of the

frequency multiplier also in development. Simplicity, reliability, and long life were expected from this approach. This design provided complete communication between 256 integrators, but proved to be extravagant in that it imposed a taxing burden upon the already heavily laden stepping memory, capacity for about 600 thousand bits being required. Communication was restricted on a later design revision in the summer of 1959, reducing the memory requirements to a more nearly reasonable 100 thousand bits.

The implementation concept for the central computer for the RV-2 advanced flight test research application system utilized the stepping strip principle for memory, microcircuits for the electronics and a magnetic means of frequency multiplication as a clocking power source. The central computer system was tentatively divided into functional modules to perform the computation for the vertical display, horizontal display, automatic control and miscellaneous functions for the low-altitude attack mission. Another similar unit was to be programmed and delivered first to provide the aircraft dynamics in a ground simulation including the other units and the display system. The computer complex was to provide communication so the units would be working as a truly central data processor. Douglas was to provide the overall system requirements. Litton was to furnish the computer system, detail component specifications and evaluation, packaging and assembly, Varo the microcircuits, and Servomechanisms, Inc., the magnetic thin film stepping strip memory.

Servomechanisms' unsuccessful efforts to produce a circulating stepping strip in 1959 pointed out the formidable problems of noise and reproducibility and the poor state of theoretical knowledge in the magnetics of thin films. Varo also had difficulty in producing microcircuits to Litton specifications. 1959 output for the RV-2 computer was limited to a few samples.

Litton Quarterly Progress Reports 21 through 24, dtd 1 June 1960 to 15 February 1961.

Litton Final Report dtd 15 February 1961.

S(2) Per Table II "Special Report—Litton Industries Progress on the RV-2 Research Application," dtd 20 July 1960.

S(3) Per Table II, Litton "Special Engineering Report—Logical Design of a Hybrid Digital Computer," dtd 3 May 1961.

Reduction in program scope in 1960 was made necessary by funding limited to approximately one half that of previous years. Objective functional requirements of the stepping strips were reduced to shorter term goals for the year. Long recirculating strips and interconnections between structures were to be electronic rather than magnetic. The linear memory strips were to be configured on 8×8 plates. Accomplishment of logic with stepping strips was deferred. Microcircuitry electronics was to be limited to a few representative circuits.

With these new ground rules a computer design was synthesized—a hybrid machine consisting of a whole number section and a digital differential analyzer utilizing circulating stepping strip registers of 3200 bits length.

25th Litton Quarterly Progress Report, dtd April 1961.

Funding for 1961 being further reduced, simpler means to demonstrate the feasibility of the RV-2 computer were sought. Effort was concentrated on a small arithmetic breadboard using 6 short-line 23-bit stepping strips for memory, 6 microcircuit read and write amplifiers and 28 microcircuit flip-flops. This would demonstrate a representative portion of the already designed long linear strip hybrid computer. A full complement of stepping strips and microcircuits was received from SMI and Varo. Write amplifiers and flip-flops were

also augmented with units from Lear. Largely because of internal connection problems of the microcircuit components a number of units failed after extended operation in checkout. Limited spares and a continual funding problem prevented operations of more than 2 of the 6 internal memory loops at one time in the arithmetic breadboard.

Litton Final Engineering Report for 1962.

This program made only slow progress in 1962. It developed that when sufficient microcircuits were available to accelerate production to a reasonably satisfactory rate, the stepping strips were found to be deficient and could not be reproduced until late in 1962, when the Douglas contract terminated. As of December 1962 all parts were available for the arithmetic breadboard and checkout was recommended to demonstrate feasibility of the RV-2 Computer, utilizing short linear stepping strips in conjunction with microcircuits. This accomplishment will represent a significant advance toward the goal of performing logic with configurations of solid state circuiting memory for a simple, reliable and easily produced computing system.

Douglas Specification 7672864.

Display Generation – Kaiser, 1958-1959

In 1958, an all-electronic Vertical Display Generator was produced by Kaiser, consisting of a simulated ground plane (contact analog) and flight path. A laboratory model was delivered to Douglas early in 1959 for a laboratory demonstration of a closed loop flight using a flight path. The Naval Air Development Center supported carry-on improvement work and ultimately Kaiser produced a model for the A2F aircraft.

Douglas Specification 7660522.

Display Generation – General Electric, 1958-1962

Although Kaiser was far along in display generation technique, full mathematical fidelity of the vertical display picture was offered by General Electric. Therefore, a contract was awarded to the Advanced Electronics Center of the General Electric Company in December 1958, per Douglas Specification 7660522. The contract, DAC 59-901, covered development of an all-electronic contact analog display generator in six phases. These phases provided for the orderly progression of the program as follows:

General Electric Final Report for December 1958 – December 1959 "Contact Analog Display Generator – Phase I (Ground Plane)," undated.

1. This phase covered the design and construction of a display generator which would generate a regular grid ground plane on a standard cathode ray tube. The ground plane would have six degrees of freedom and real time response to variations in these dimensions. The generator would consist of breadboard equipment and would be used to demonstrate engineering feasibility only.

General Electric Report "Appendix to Contact Analog Display Generator Phase I (Ground Plane) Final Report for December 1959, Detailed Circuit Descriptions," undated.

General Electric Report "ANIP Flight Path Generator Final Report and Maintenance Instructions (Phase II)," undated.

2. This phase involved the design and construction of equipment capable of generating a planar flight path. The flight path generator would also consist of breadboard equipment solely for demonstration of engineering feasibility. Generation of the display on a standard cathode ray tube would constitute successful demonstration.

3. This phase provided for a study to determine the feasibility of satisfying the display requirements for a ground plane having a random texture.

General Electric "ANIP Contact Analog Generator Final Report (Phase III)," dtd January 1963.

4. This phase consisted of studies to determine the feasibility of satisfying the display requirements for a sky plane, a velocity track, encodement of terrain clearance information, and additional symbols.

5. This phase involved the design and fabrication of equipment which would supply video inputs to a display unit. It would generate a display including features established under the first, second and third phases. The equipment would be used primarily for simulation work but would be readily adaptable for flight test use with a minimum of modification.

General Electric "ANIP Contact Analog Handbook of Operation and Maintenance Instructions" (due approximately March 1963).

6. This phase would terminate the project and would consist of the design and fabrication of a display generator incorporating the advanced concepts and techniques resulting from the preceding phases.

The first phase was successfully completed in December 1959. In an effort to offset the delays in the project which were incurred during this phase, the requirements of the second phase were changed to include delivery of laboratory equipment. Since technical difficulties also delayed this phase of the work, the next follow-on with General Electric also attempted to compensate by jumping to a modified version of the fifth phase. This modification work involved delivery of an all-digital-stored map (irregular texture) contact analog generator, an integrated flight path generator-coordinate transformer unit, and a common input section serving both units. The units were specifically intended for laboratory use, hence ease of access and reprogramming flexibility were stressed. The contact analog generator was an entirely new unit but the flight path generator featured a modified (but still planar) version of the unit delivered under the second phase. Douglas was in the initial phases of the experimental evaluation of these units when the prime contract was terminated.

Display Generation — Avion, 1958-1959

Attempts to use the quickly developed mechanical horizontal display map plotter by L. E. Setzer and Co. on the T2V flight test emphasized the need for more adequate map display with large coverage, scale changes and integration of radar data and other symbols with the map. These requirements were developed and set forth in specification 7660521, originally issued in September 1958, and industry was invited to respond. The Avion Division (now known as ACF Electronics) of ACF Industries was awarded the contract. Need for a flyable unit stimulated development of a servoed map slide unit with optical readout by means of a television camera. Equipment was delivered to Douglas early in 1960. Study of the scan conversion problem to make radar scan rate compatible with television did not result in improved methods. Consequently, implementation of a scan converter utilized a cathode ray storage tube in combination with a television camera. Later this problem was partially solved by Kaiser on their own, with a solid-state scan converter. The need for such makeshift solutions has since largely been eliminated with the advent of high-speed scan radar as later studied by D. Young on the Army-Navy Instrumentation Program. Symbol generation was effected for 13 symbols by means of electronically producing Lissajous figures and multiplexing them with a commutator on a CRT.

Litton Quarterly Progress Reports, 22 through 25, dtd 1 August 1960 through April 1961.

Display Generation — Litton, 1960-1961

Display function generation directly by a computer was simulated by Litton in the form of a flight path display during 1960, and during 1961 a small digital system was breadboarded to drive the display.

SENSORS

Reasonable limits for the sensor area of the man-machine system were hard to delineate. This circumstance made it difficult to communicate to those engaged in the research to the practicable extent to which they should pursue their studies. As the effort summary unfolds, it can be noted that this hazy definition existed for over half the program. The problem cannot be entirely resolved by reference to the dictionary, since the terms "measuring instrument," "sensor," "receiver," "transducer," and, finally, "coupler," are not precisely defined.

Early in the program it was noted that, if data processing requirements of the system were to be met, both new and improved means needed to be found to "convert" the information contained in the man-machine environment to the internal language and physical state of the data processor. Without sharply dividing the two, the program began with investigations into several sensor areas where improvements were desired. It wasn't until the work was performed later in the program of fundamental sensor philosophy and classification that the situation was clarified.

The initial plan was to make an order of magnitude improvement in the sensors that were to provide attitude, air data, and fuel quantity data to the computer. It was anticipated that this general class of sensors would be required even if a basic classification scheme could be devised for the sensor area.

Consequently, early in 1954, eight specifications were submitted for bid. The requests covered the following areas: air density, temperature, signal transmission, gyroscopes, fuel flow, airspeed, and angle of attack. The replies ranged from mildly interesting through extremely conventional, but none presented a unique approach to research in the sensing field. The fuel sensing, airspeed and angle of attack determination proposals offered only developmental approaches, so contracts were not awarded at all in these areas. The remainder offered enough promise for improvement to the existing technology to warrant the award of contracts for limited studies. The studies were to determine a feasible approach and provide analytical support for subsequent construction of an experimental model. Evaluations were completed and contracts let in mid-summer 1954.

Douglas Specification 7447633, "Gyroscope Development," dtd January 1954.

Honeywell Proposal No. R-ED 9713, dtd April 1954.

Upon evaluation of the responses to the specification for an improved gyroscopic element for potential use in an inertial sensing system, it appeared that Minneapolis-Honeywell had both an intimate knowledge of the problems of construction of an "ideal" gyro and approaches to their solution. M-H outlined those improvements that would make a major contribution toward performance improvement and miniaturization:

- Use of heavier flotation fluids
- Use of increased wheel speeds
- Improved gimbal suspension
- Development of limited function torque and signal generator

- Improved gimbal balancing system
- Improved fluid fill techniques
- Optimization of angular momentum
- Lower viscosity flotation fluids
- Three-gimbal housing (special for platform use)
- Improved systems circuit techniques

During the course of the program two additional areas were uncovered as contributing to the improvement of performance.

- Determination of optimum flex leads
- Minimization of drift torques due to aniso-elastic gimbal and motor design

The final design was the result of a two-year study of these variables and the state-of-the-art contributions that M-H achieved. Significant design features included:

Honeywell Quarterly Progress Reports No. 1 through 7, dtd November 1954 to May 1956.

1. Heavier Flotation Fluids: A number of elemental, organic, inorganic fluids with specific gravities of from 2 to 6 were investigated for possible use. M-H personnel contacted chemical research facilities in a number of companies and universities without success. A requirements study did develop a specification for an ideal fluid. These data were forwarded through ONR for submittal to NRL and the National Bureau of Standards for possible assistance.

   A company funded program in M-H of four years duration did not uncover a significantly improved fluid, so the normal fluorolub compound was utilized.

2. Increased rotor wheel speed: The then optimum rotor speed of 12,000 rpm could be improved to a value of 48,000 rpm within the limits of the bearing materials and gimbal supports. Fifteen experimental spin motors were operated at 30,000 rpm successfully for 7,000 hours at temperatures up to 300°F. It was deemed necessary to design the improved gyro for 24,000 rpm since this happened to be the highest synchronous speed obtained directly from 400 cycle power — expected to be the prime power for aircraft use.

3. Improved gimbal suspension: The major technologies of mass restraint were surveyed without too much success. The advantages of suspensions such as crossed reeds and hydraulic systems are outweighed by the disadvantages for this particular gyro configuration. Magnetic and torsion bar techniques were not applicable. The contemporary pivot and jeweled bearing suspension proved to be the superior design.

4. Function torque and signal generators: A general study of torquing devices and also methods of signal detection including optical, capacitive, and radioactive. Many detection methods have definite space and weight advantages over inductive pickups when considered alone. The addition of the requirements for rotor torque as well as position pick-off favored the design of a combination device. The Dualsyn provided a 50 dyne-cm. max. linear torque with 0.5% linearity while acting as a signal detector with a sensitivity of 1.0 millivolt per milliradian. This unit as packaged in the gyro occupied a 1.5 in. diameter by 0.44 in. long space.

5. Gimbal balancing and fluid fill techniques: These two problems are in reality only one. The balancing of the gimbal outside the case can be easily accomplished. Once inside the case and filled with flotation fluid, anomalies in the fluid and bubbles trapped inside the case account for the majority of unbalance problems. An adjustable balance system that was accessible through the bellows seal was utilized. A technique of out-gassing the gyro and the flotation fluid by heating both in a vacuum chamber prior to and during filling, all but illuminated the bubble problem.

6. The determination of optimum angular momentum: The best summary can be achieved by quoting the Honeywell final report: "The optimum selection of angular momentum is determined through a compromise between two conflicting trends. At the lower limit, the angular momentum must be large enough so the equivalent drive rate of all unwanted torques about the output axis does not exceed the desired gyro drift rate. At the upper limit, the mass of the motor and gimbal structure required to obtain the angular momentum must be small enough so the equivalent drift rate produced by the combined effects of ambient vibration and anisoelasticity of motor and gimbal housings does not exceed the desired drift rate. The compromise is further complicated by the fact that unwanted torques determining the lower limit (such as mass unbalance) increase with increased gimbal structure size and mass . . . . . . System and gyro analysis shows that elastic restraint is the most critical factor in determining minimum permissible angular momentum. Based upon the above considerations a momentum of 100,000 gm-cm^2/sec. has been selected as the best calculated value for a gyro drift rate of one degree per hour."

7. Lower viscosity damping fluids were analyzed extensively but not used. Analog computer studies indicated that the platform servo loop would be oscillatory unless the gyro damping could place the gimbal transfer function below 5:1. The only way to maintain stability would be through increased use of electronic circuitry external to the gyro: an impractical procedure.

8. The manufacturing and service difficulties of a single housing for a three-gyro system for use on a platform could not be compensated for by the slight decrease in platform package size. The design study was therefore terminated.

9. A compensating circuit was designed permitting the gyro to operate from existing 400-cycle power sources on the aircraft, thus eliminating the necessity for further regulation at a cost of equipment and reliability.

It can be noted that except for the dualsyn design, the creation of the MIG (miniature integrating gyro) was due entirely to refinements to existing technologies of a floated gyro design.

Honeywell Final Report No. AD5283-TRI, dtd 31 December 1956.

The engineering objectives of one degree per hour uncompensated drift, 1.75 in. diameter, 2.2 in. length, and weight of 0.5 pounds for the final unit were almost achieved. The gyro was a successful improvement in the state of the art and led to a number of production applications. The final performance figures were: 1.75 in. diameter, 2.5 in. length, 0.48 pound weight and a total uncompensated drift rate of 1.9 degrees per hour.

Douglas Specification 7446776, "Temperature Sensing Element," dtd 18 September 1953.

Eclipse-Pioneer Proposal No. 7932-54-5, dtd 14 April 1954.

Servomechanisms Proposal No. 471, dtd 12 May 1954.

The response to the Douglas specification for a temperature-sensing study included twelve proposals, six of which were considered to meet the objectives of the investigations, which were: Arrive at (hopefully) a single temperature sensing device that might be used in all fluid and gaseous media encountered in conventional aircraft. This could eliminate the numbers of types in current use. Emphasis was placed upon accuracy and simplicity for the final project.

The Douglas evaluation analysis was unable to separate technically the top two proposals. However, on the basis that the study effort and understanding of the problem were highlighted by the Eclipse-Pioneer Division of Bendix and the hardware aspects were proposed by Servomechanisms, two contracts were awarded.

Eclipse-Pioneer Report No. 1 — Study Phase, dtd 21 February 1955.

Eclipse-Pioneer (EP) was to consider the elementary concepts of temperature, review the literature on temperature measurement, kinetic heating, shock wave formation, and general heat transfer phenomena, and finally make comparative analysis of the techniques that would permit the realization of the program objectives. If new ideas were to come from this study they would be considered as follow-on effort.

Eclipse-Pioneer Report No. 2 — Final Study, dtd 15 June 1955.

In the course of the study, a summary was prepared listing the requirements, existing methods, present development and finally the research required regarding temperature-sensing devices. The conclusions indicated:

1) A single sensor that could operate over the range -100°C to 1400°C was not practical at the time. Three were recommended: a) the environmental class of still gases and liquids up to 500°C; b) free air up to 500°C; and c) high temperature range for such things as combustion gases.

2) Two categories of sensors that require heat transfer and those that do not (thermocouples versus velocity of sound or orifice flow measurements) are the only known techniques for measurement. The kinetic energy transfer from the medium to the sensor may remain as the best method.

3) The most serious problem has not been solved nor an approach conceived. This is the situation that the sensor only indicates the temperature of those molecules that impinge upon the device and not necessarily the average value for the mass being measured. This is particularly true for high velocity combustion product temperature measurement in heat engine applications. This problem was beyond the scope of the effort.

The contribution of this study was primarily in clarifying the state of the art in temperature measurement. The true value of temperature sensing for a particular situation in aircraft was not successfully uncovered. The problem was dropped following this study until a new approach could be found to classify the sensing area.

Servomechanisms Progress Report Nos. 1 through 3, dtd 7 January 1955 and 14 March 1956.

The parallel work at Servomechanisms on temperature sensing revolved about a technique that Servomechanisms had developed for manufacture of thin film potentiometers. The technique involved vacuum deposition of an extremely thin high temperature metallic film on an equally high temperature ceramic cylinder in the form of a helical ribbon. Tests were performed using a number of materials for both the base and the resistive element. The final configuration utilized a refractory magnesium silicate (Alsimag 222) or pure Al_2O_3. The vacuum deposited film was platinum. The platinum was protected by a thin deposition of Alumina (Al_2O_3) to prevent contamination. The final configuration was a ¼ in. diameter cylinder, under 1 in. long with a resistance of 10,000 ohms. The elements did see some limited operational use when one was used in the T2V (RV-1) flight program in a total temperature probe. The elements did not achieve production significance. However, the data gathered, experience, and interest in the ANIP approach made Servomechanisms a key team member in later materials, microcircuitry, and vacuum technology research.

Douglas Specification 7447901, dtd 30 March 1954.

Control Instrument Report (with Supplementary Bibliography), dtd May 1955.

Another area that was considered to be important was that of direct sensing of air density. Many of the complications of jet engine performance control, navigation, and aerodynamics required the computation of air density from other air data such as pressure and temperature. The number of sensors and the quantity of data processing could be reduced by this direct measurement. Seventeen proposals were received in response to the specification, and Control Instrument Corporation was selected for a six-month preliminary study. (This preliminary study, it should be noted, constituted only the initial phase of CIC's more comprehensive proposal; as outlined, the second phase proposed to correlate analytical data derived via first-phase efforts with information gleaned from previous upper atmosphere measurement programs.)

Two approaches were undertaken, the analytical and the empirical. The former explored the thermodynamic

relationship of atmospheric gases; the latter, dependence of these gases on actual quantitative composition for preservation of accepted standard physical properties.

This study comprised the following principal items: (1) Density distribution, depicted as a function of altitude (derived theoretically from an application of gas laws and the solution of applicable hydrodynamic equations); (2) a discussion of possible effects of turbulence and composition anomalies as a result of ionization phenomena (since these effects could not be mathematically accounted for, this aspect of the research effort was inconclusive).

A parallel effort surveyed known and conceivable methods of sensing air density. Of the eighteen methods considered, Selective Absorption, Index of Refraction, Mass Spectroscopy, Slow Neutron Scattering, and Soft X-Ray Absorption were selected as the most promising. Further study revealed Mass Spectroscopy as the best but unfortunately the technique most difficult to mechanize for airborne use. The application of this device is limited to altitudes above 20,000 feet so that another means must be devised for the lower altitudes.

Control Instrument Final Report DEV-9759, dtd June 1955.

As the study drew to a close, it became apparent that, for the present, continuation of the effort would be unproductive. Principal support for this conclusion was derived from the lack of specific and conclusive data on the state of the upper atmosphere, and the severity of mechanizing a mass spectrometer less complicated than the existing pressure sensor and computer equipments presently required for air density determination. Work was terminated with the desire to survey the problem again at a later date.

Douglas Specification 7447628, "Synchro and Servo Motor Development," dtd September 1953.

Included under this area of sensor is an analytical study and equipment feasibility program to improve synchro and servomotor devices that were then key elements in many aircraft subsystems. Of six organizations that responded, an evaluation indicated a superior approach by the Norden-Ketay Company (now Norden Division of United Aircraft). A contract was placed for a six-month study effort.

Work had barely started when a conference was organized at the Office of Naval Research by the ANIP (then IID) Scientific Officer for October 22, 1954. Discussions at an ONR orientation conference the previous week had suggested a broader approach to this particular study. Consequently, Norden-Ketay was directed to investigate the broader field of signal transmission and components. Similarly, Douglas was to revise the original specification to cover the new work. The specification was entitled "Signal Transmission Development" and requested.... "development of improved methods of signal transmission to be used in aircraft systems. The signals to be considered are those derived from sensory devices... etc." Compatibility with computer and display equipments was another requirement.

Norden-Ketay Quarterly Progress Report No. 1, dtd June 1954.

Norden limited their own effort by eliminating audio and visual information from initial considerations. The classes of signal transmission devices were determined and both signal sources and responses at

the molecular level were tabulated. A statement of the following fundamental requirements constituted the basis of their first report:

- Detect physical or chemical changes at a source
- Convert these changes into signals capable of being transmitted
- Reconvert the signals at the opposite end of the link into reproduction of the original signals or into some other physical or chemical response.

Norden-Ketay Quarterly Progress Report No. 2, dtd April 1955.

The second report revealed that electrical transmission links were best for aircraft applications. From this assumption, two categories of transducers were indicated; those used to produce a variable impedance in a circuit and those used to produce a source of variable electromotive force (voltage).

Through analysis of signal conversions typical of aircraft subsystems, the majority appeared to be mechanical to electrical conversions. Emphasis was then placed on this class of device. The study came close to the original objective — synchros and servo motors. Norden suggested that a synchro system is somewhat ideal from the viewpoint of simplicity and that a system combining this simplicity with the accuracy of servos would be a definite improvement.

The first category of transducers, those that produce a variable impedance, was determined to have definite advantages over variable voltage devices from these considerations:

- Two wires instead of four
- No power at signal source
- Intermediate conversion of signal eliminated
- Minimum size and weight
- No brushes or slip rings
- High efficiency

Combining variable impedance and variable voltage and introducing a third variable, the use of a central digital computer as the probable receiver of most of the signals, produced the requirement for a variable impedance device to convert mechanical motion to an electrical signal usable by the computer. Norden had a design for such a device called a Chronosyn.

Norden-Ketay Quarterly Progress Report No. 3, dtd September 1955.

The Chronosyn puts out two pulses during each revolution of a synchronous motor. The time interval between the pulses is proportional to the angular position of the input shaft. Similar pulses are put out by the receiver as a time reference.

Some additional advantages of the Chronosyn are:

- Digital form of output compatible with digital computer
- Several remote receivers would not load a single transmitter
- Reliability greater than a synchro
- Fewer interconnecting leads than the synchro system
- Low friction torque
- Miniaturization potential greater than synchro

Norden-Ketay Quarterly Progress Report No. 4, dtd February 1956.

Norden-Ketay Quarterly Progress Report No. 5, dtd July 1956.

The significance of these advantages was not determined because of a change in requirements from the central computer research group, namely that pulse train inputs could not be processed. Norden very quickly came up with an alternative scheme. The new device, called a Diosyn, converted angular shaft position to a variable frequency. A Van Allen variable frequency oscillator circuit was slightly modified by use of a cam-shaped soft iron shunt to effect the flux in the circuit's magnetic cores. The basic Van Allen circuit functions by alternately saturating each of two magnetic cores. The operating frequency was dependent upon the cycle time required for the cores to reach stauration. The influence of the iron shunt was to alter the flux distribution and therefore the output frequency. For the specific requirements of the system, the cam was shaped to produce linear and functional outputs. Since frequency was the transmitted variable, the Diosyn had these advantages:

- Not subject to degradation during transmission
- 2 wires only required in link
- Low friction torque (shaft support bearings only)
- No errors due to loading
- Multiple receivers per transmitter possible
- Easily telemetered output signals
- Compatible with ANIP computer

Norden-Ketay Final Report, dtd February 1957.

Subsequent work by Norden through mid-1956 was directed to improvement of the Diosyn for potential use in the T2V (RV-1) flight test program.

Problems of output error due to line voltage, temperature, and shaft end-play were analyzed in this period. Two Diosyns were delivered with these characteristics:

Input 28 volts d-c
Accuracy ±1%
Repeatability ±1%
Frequency change due to 10% change in line voltage ±1%
Length 2.54 inches

Diameter 1.062 inches
Weight 4 ounces
Output 257 to 935 cycles per second at 0.15 volts rms

The program was terminated with a demonstration of the feasibility of the approach. Funds were not available at the time for further analysis of new signal transmission concepts.

From the later months of 1956 through early 1959 no subcontract work was performed in the sensing area. Both technical and financial problems contributed to this interruption. The state of the art had been advanced somewhat by the early ANIP efforts, but not significantly so. No new conceptual approaches had been uncovered by the five subcontractors previously chosen from the numerous proposals.

Douglas Specification 7553925, "Stable Inertial Platform," dtd June 1953.

System Analysis personnel within Douglas were continually analyzing requirements of the Data Processing investigators for sensing improvements. Problems of Data Processing were extensive enough in themselves and therefore no new or more demanding requirements were established at this time. It was considered appropriate to capitalize upon the results of the Honeywell Gyro experience and release a specification for the design analysis of an inertial reference platform. A specification was prepared by Douglas based upon analysis requirements for performance and released for bid. Of the eight companies responding, four were found to have definitely superior ideas. The final choice was Litton Industries. One of the facets of their design that contributed to weight and volume estimates 20% lower than other bidders was the matching of the platform to the digital computer (then under contract). The program never went beyond this evaluation stage due to funding commitments to the display, data processing and human factors program then underway. The general analysis of this problem of sensing was again absorbed by DAC in their overall system analysis efforts.

During this period both ONR and Douglas personnel attempted to provide a degree of order to the sensor area by establishing a simplified classification scheme. Sensing functions were divided into electromagnetic, inertial, force, geometry, temperature, and quantity categories. Each of these was to be further analyzed and classified prior to any new component development efforts.

Another hypothesis was raised by ONR and Douglas that was later to be investigated by the Benson-Lehner organization. System components, especially the sensors, were considered energy transfer devices and a general classification was to be formulated to enable basic systems and materials to be viewed as energy transfer mechanisms. Energy transformation is not a particularly unique concept except as applied to the analysis and design of improved or optimized systems. A radio receiver, for example, converts electromagnetic energy to sound energy. There is no device presently that can perform this operation in a single transform apart from a crystal. Although this objective may never be completely achieved, it does point out that the present electrical, electromechanical and other intermediate conversions represent possible steps that research might eliminate. Benson-Lehner studied the prospects of such an approach but

together with ONR and Douglas were unable to suggest a methodology to attack the problem in more detail. It was not until later work by Servomechanisms, Inc. on basic materials research (Ref. Section 8) and Motorola on inertial sensor classification that an approach was suggested. Servomechanisms attempted to classify known physical effects which were observed energy transfer phenomena. The program was brought to a close before the entire methodology was formulated.

Another contributing factor to Douglas absence from the sensor area during this period was the coordination arrangement that existed between Bell Helicopter, rotary-wing coordinator, and Douglas. Close liaison between these organizations was to insure no duplication of effort. Bell did have several research projects in inertial sensing, air velocity, and electromagnetics at that time.

In 1960 a most interesting unsolicited proposal was received from D. W. Young and Associates outlining a technique for integrating information directly with the contact analog. With the concurrence of ONR, an exploratory contract was let to Young & Associates to pursue this subject. Young and Associates were aware that the contact analog superimposed upon the real world via a flat CRT or equivalent display medium would have to be supplemented with electromagnetic (radar) information. Current techniques involved elaborate scan-conversion devices to convert radar scan rates and target return rates to standard television for superposition in the display. The Young technique was to increase the scan rates of the radar by use of a rapid scan antenna for azimuth and an interferometer technique for high data rate in elevation. The high rates eliminate the requirement for conversion equipment since the data are interlaced with the television directly.

D. W. Young & Associates Report No. 301 (Parts 1 through 5), dtd May 1962.

It is obvious that with a limited bandwidth the increased rates could not be achieved without a sacrifice of other performance factors, such as resolution. This is not a serious problem when the objectives of this system are axamined. The intent of this sensor-display system was to provide gross terrain information correctly oriented in elevation, azimuth and roll with the real world and/of contact analog presentation on the display. This consistency required that the position and motion of elements of the sensed world were identically those of the actual world as presented on the display. In addition, it is a characteristic of such a display that only those elements of the display that do not move are coincident with the flight path vector of the vehicle. This suggests the overwhelming importance of the motion cues in the display and in the sensed data. The explicit detail of the terrain feature is far less important to obstacle avoidance than the relative motion as seen in the display. This is not the type of radar required for target classification but is excellent for terrain avoidance.

An experimental model of this type of sensor was constructed and demonstrated for proof of feasibility in 1961.

In July of 1961, a program to develop a classification methodology for inertial sensors was transferred from Bell to Douglas at ONR request. This study had been in effect for over a year and was the result of a Bell specification for a means of classifying inertial sensing components in a form that could possibly lead to new and profitable research. Such a logical grouping should provide:

1) Performance limits by group or classification

2) Possible alternative of design

The Motorola study first identified the boundaries of sensor phenomena by establishing that: "sensing is the first physical change within the instrument predictably related to the external physical quantity being measured." This is consistent with the related energy transfer philosophy pursued by Benson-Lehner. The initial set of principles for the classification were: the equation of motion; measurement and constraint technique; and, the material of construction.

Bell had concluded that future requirements for sensors could not be met by some of the existing techniques and devices. Before seeking a profitable path a study effort was envisioned that would determine the fundamental factors that govern sensor performance; initially, the inertial sensor system. Motorola suggested in their proposal that cost in terms of both time and money could be saved in research and development of new sensors if physical theory could be systematically related to the quantity being sensed and to the techniques of sensing. If a classification scheme could be devised and the basic natural limits of each class determined, then there could be a means of predicting performance of a specific design. A methodology was developed after four unsuccessful attempts and Motorola proceeded to verify the system by entering specific examples into the classification from a survey of instruments and techniques. Data were gathered on 290 inertial devices; 200 of these were documented. The classification scheme represented a major tool for the analysis and prediction of inertial performance.

Motorola Report RL-TR-3846-5, "Classification of Inertial Navigation Sensors," dtd August 1961.

Motorola Report RL-TR-3846-1, "Nuclear Magnetic Relaxation Times," dtd August 1960.

Motorola Report RL-TR-3846-2, "Field Supported Rotors," dtd December 1960.

Motorola Report RL-TR-3846-3, "Informational Aspects of Sensor Operation," dtd March 1961.

Motorola Report RL-TR-3846-4, "Nuclear Magnetic Resonance Rate Gyro Performance," dtd April 1962.

As part of this classification effort it became apparent to Motorola that current R&D in inertial devices was concentrated primarily in devices using atomic or sub-atomic particles or phenomena as the basis for the design. Certain aspects of performance were obtained by this general limits approach for seven physical systems that could be considered as inertial receivers (sensors). These were: 1) a bound atom; 2) ionic and sub-atomic particle beams; 3) a rigid body with a linear restoring force; 4) a free rigid rotor; 5) a single crystal; 6) a gas sample, and 7) atomic and sub-atomic spin systems.

It was during this period while these parallel studies were under way, that the contractual coverage of this program was shifted from Bell to Douglas auspices. Quarterly reports were discontinued and replaced by a series of technical documents covering these parallel studies. The results of these seven studies are therefore spread between the original Bell Quarterlies and the Douglas-sponsored technical documents.

The significance of the studies can be stated by quoting Motorola's first Summary Report of June 1960: "We have found that the Heisenberg uncertainty for a vehicle acceleration computed from the relative displacement of ionic or subatomic particle beams is on the order of 10^{-4} gravities." And, . . . "kinetic theory of matter . . . . the minimum uncertainty . . . . for relative displacement of a solid with a linear restoring force is about 4×10^{-8} gravities at 18°C." This has implications of potentially better performance for certain contemporary techniques than for nuclear gyros.

MATERIALS AND TECHNIQUES

Throughout the investigations of the basic functional blocks of man-machine system by the numerous investigators of the ANIP program, problems continually occurred related to the materials to be used for the construction of the units and to the techniques for their manufacture. Many concepts were never demonstrated due to the constraints provided by the lack of knowledge of basic materials. It was the objective of the initial phase of research to accept the functional requirements of the display, data processing, sensor, and control investigators and use these requirements to establish a direction to the material efforts.

It was during the early discussions of the area of materials research that Mr. Austin Stanton, President of Varo, Inc., put forth an idea (later formalized in proposal No. 1914 in 1953) regarding the concept of microcircuitry. The concept of microminiature components is not unique. The Varo proposal did, however, conceive of a technique that would make microcircuits possible. It is suggested that minute amounts of materials that exhibited directly or via configuration the basic electrical properties could be deposited upon an insulating substrate material in the form of an electronic circuit. Stencil masks would confine the deposit to the desired circuit paths. The potential of this concept so stimulated ONR and Douglas personnel that an exploratory contract was placed with Varo in 1955. Subsequent work by Servomechanisms, Litton, Kaiser, and Douglas not only contributed to this technique but added some new concepts of their own. This section will cover in summary form these contributions from two viewpoints—Materials and Techniques.

It appears that the problem of Techniques occurred before that of Materials. The Varo concept of microcircuitry was, of course, a technique for the creation of microcircuits, but utilizing known materials. As will be noted, the Varo organization generated the first material problems. The initial one-year program with Varo was an investigation of the effects of resistive and insulative thin films in a vacuum. It was at this time that the word "microcircuit" was coined to describe the individual circuit wafers that would exhibit some electrical function or characteristic at a higher order level than elemental components. The objects of long range interest were:

1. The ultimate microminiaturization to result from the functional usage of each atom of the fabricated device and the elimination of all superfluous material.
2. The highest degree of reliability to result from the optimum utilization of the fundamental properties of matter and the elimination of human factors such as connection and assembly operations.
3. The minimum cost of design, fabrication and use of microcircuitry devices will result from the transfer function approach to design. This approach would permit the complete automation of manufacturing, proceeding from relatively inexpensive raw material to the functioning device. The establishment of the throw-away concept as a more economical practice would be possible.

The fabrication concept of microcircuitry is essentially based upon the vacuum deposition of materials. The first logical step toward the ultimate microcircuitry technology was considered to be the vacuum

deposition of thin films of the various materials required to provide the functional electronic circuit parameters. A review of the literature indicated that although extensive research efforts had been made with thin films, relatively little was known of their fundamental properties and the factors controlling such properties for the purpose of the microcircuitry requirement.

Varo Quarterly Progress Reports 1 through 17, dated August 1957 – December 1960.

A second important design concept in the microcircuitry technology has been the application of the transfer or describing function to the analysis and design of circuits and devices. The input-output relationships of any network or device may be defined in terms of a set of describing functions. Since in the microcircuitry technology it is possible to monitor and control the arrangement of deposited materials until the exact performance required is obtained, it is practical to apply the transfer function concept to both the design and fabrication of electronic devices.

As the transfer functions for various networks are determined and/or as the networks for various transfer functions are synthesized, design tools become available to the engineer to simplify and shorten his design efforts.

In order to construct complete circuits, it required that conventional semiconductors be used in conjunction with the deposited passive circuitry. In standard form, however, the transistor or diode is a relatively huge device. Standard type transistors were analyzed to determine the feasibility of assembling them into the microcircuits without their cases. Coatings of various materials were tried as a protective measure. Although this met with some success, a more direct process such as deposition of these active elements was a preferred approach.

A similar intense effort was under way to deposit the single crystal of semi-conductor material so as to decrease the volume required by that element, to eliminate the assembly operation, and to make semiconductor processing compatible with the concepts of microcircuitry.

It was an objective of the Varo microcircuitry program to develop a design handbook of transfer functions together with the associated morphology of materials which will provide such functions.

Morphology is, itself, still a third design concept of microcircuitry, morphology being the physical arrangements of materials within the microcircuitry device.

Douglas Specification No. 7668676 "Microcircuitry Development" dated August 1957.

Initial work involved the determination of ways to deposit the two basic passive circuit elements, the stable resistor and dielectric materials, to constitute capacitors. Approximately half of the total Varo effort was spent on the materials and technique required for successful deposition of these. The other half concerned circuit layout; the types of circuits amenable to reproduction by vacuum deposition; and the methods of design and operation of the high vacuum equipment to produce satisfactory results.

To meet the demands of the computer program and to establish several basic circuits for initial investigation, Litton prepared performance specifications and equivalent circuit information for Varo. Original computer design required that at least three functions, write amplifier, read amplifier, and a bi-stable "flip-flop," be built.

The simplest microcircuit has been the four-transistor write amplifier produced by Varo. The reliability has exceeded the other microcircuits. Of ten units fabricated, nine have remained operable (90% yield). Five units have received over 1000 hours of intermittent and steady operation attached to the Litton multiple-laminate interconnection board. These checkout tests were conducted at room temperature without supplementary cooling air.

The read amplifier units manufactured are more complex with three stages and six transistors. Five of twelve units fabricated have failed under operating conditions similar to the write amplifiers (58% yield).

The most frustrating, and yet the most rewarding segment of data gathered, has been that relating to the flip-flop units. The design created by Litton is a six-transistor component comparable in complexity to the read amplifier. The most advanced transistors as of 1959 were secured from Fairchild in an uncased form. They were attached to the deposited circuit via conductive epoxy. To reduce the number of interconnections (a major source of circuit failure), four flip-flop substrates were packaged and encapsulated in a single module. Thirty-six individual flip-flops were tested and evaluated at Litton with about twenty-one remaining operable (58% yield). Approximately 16 were operated over 900 hours intermittently at room temperature. Since the units are packaged into modules of four, the actual yield from an operational standpoint has been 2 out of nine, or only 22%. One package has 24 transistors, 64 resistors, and 16 capacitors. The picture of the yield from subassembly stage at Varo through evaluation stage at Litton is somewhat less encouraging. Out of 52 in subassembly, only 21 survived evaluation testing at Litton. In terms of module packages, the yield was therefore 2 out of 15, or 15%.

The use of conducting epoxy was the cause of the most failures because it introduced unwanted resistances at connection points. In two packages, failures occurred in all four flip-flops. Although conducting epoxy was used in the write amplifier, the effect of the resistance change did not have such a serious consequence as in the flip-flop. The fabrication techniques using epoxy are somewhat difficult. This became apparent to Varo late in 1961. Thermo-compression bonding was found to be a better, and also an easier-to-use technique. Other workers in microcircuitry have since reported the same findings. This technique was used by Varo in the last two packages they produced. Failures attributed to excess heating are labeled "Design Faults." It might be noted that causes for some of the failures have not been established. This situation is partly due to the cursory evaluation that was made because of time and money limitations; secondly, the encapsulation material prevents thorough dissection without inadvertent physical damage. Partially failed packages are used in the demonstration computer. Although it is promising, only continued performance testing will validate the thermocompression-bond method of connecting circuits.

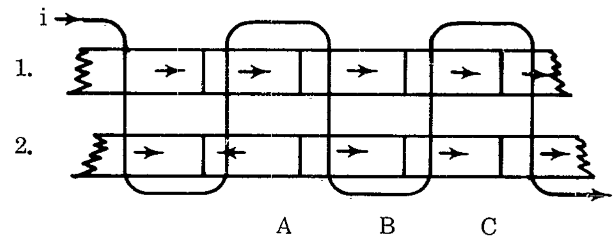
This foregoing evidence indicated a need for some design changes to be made in the flip-flops. Since lower power and more consistent active elements soon were available from the transistor manufacturers, internal heating was reduced to at least one half. In the stretchout of this computer feasibility effort, the Litton organization was the only one of the group (Servomechanisms and Varo) that remained under direct contract for this effort. The others have been relegated to suppliers of parts. This somewhat complicated the team arrangement that had been so successful in the early study and design stages of the computer program. Servomechanisms provided stepping strips and Varo microcircuits through direct purchase order from Douglas. Lear was introduced into this effort near the end of 1961 as a backup and alternate supplier to Varo. These units were similar to those that Lear had placed into production. This was indicative of the rapid growth of microcircuitry throughout industry. At the time Lear was only one of 22 major companies actively pursuing microcircuitry. This acceptance factor, plus the narrowing of program-subcontract efforts due to funding, forced the closing of the Varo work in the summer of 1961.

The currently demonstrable capability of microcircuitry, to permit fabrication of a variety of electronic devices with high equivalent component densities, by no means approaches the ultimate objectives, although it is a substantial advancement over conventional techniques.

Today microcircuitry can result in component densities well upward of one million parts per cubic foot, but as increased knowledge and improved techniques permit the more effective use of the basic functional properties of each particle comprising a microcircuitry device, the capability climbs towards what appears to be an ultimate density greater than 10^{10} parts per cubic foot.

Servomechanisms Progress Reports Nos. 1 though 12, dtd Nov. 1957 through Nov. 1960.

The other important technique contribution was made by Servomechanisms again in support of the computer research under way at Litton. As part of the team approach, Servomechanisms (SMI) investigated the requirement for a new type shift register that would be smaller, more reliable, simpler, and much cheaper than anything heretofore available. A brief study indicated that a solid state approach was definitely required, and a survey of possible technologies led to a decision to pursue thin evaporated magnetic films. In the course of this development of the stepping strip concept a great deal of basic research was done on the behavior of magnetic thin films, and an understanding of the phenomena they display. One factor in the successful operation of the stepping shift register is the principle of domain interaction. The magnetic domain interaction stepping register progresses digital information through a continuous evaporated permalloy film by means of the action of one magnetic domain upon another neighboring domain. This action can best be shown by illustration:



Each film strip area is arbitrarily divided into sections or domains A, B & C magnetized initially as shown. Cell B is locked in place by the magnetic state of cells A & C. If cells A & C are magnetized into opposite states the total effect on cell B is neutralized. Cell B in the first figure would be difficult to "flip" while Cell B in figure two would be easy to "flip." This is domain interaction. If conductors are deposited at right angles to the domain "easy" axis (the preferred direction of the magnetic poles, in this case along the film), a current pulse on this "clock" winding, plus the magnetic effect of adjacent domains, will cause reorientation of the film domain in question. By the proper spacing of conductors, digital words can be continually stepped along a magnetic film, domain by domain. A great deal of data is available on the magnetic properties of 80% Nickel and 20% Iron ferromagnetic alloys and consequently this material was initially used for film depositions. A magnetic field is applied to the substrate area during deposition in order to orient the "easy" axis of the film parallel to the direction of stepping.

Two parallel programs were carried on: the theoretical aspects of film behavior and the application of the films to stepping registers for the computer. A mechanical analog for the behavior of domain wall motion evolved. The model permitted the derivation and verification of data previously obtained experimentally. This has been an extremely valuable tool for magnetics research.

Basic research into behavior of nucleation (the formation of domains) in magnetic thin films, determined the minimum conditions of magnetic field to cause nucleation and growth. Sensitivities below values of the earth's magnetic field were observed. Imperfections in the glass substrate were the source locations of nucleation and smoother surfaces will have to be obtained so that this phenomenon may be more closely controlled. Smoother glass being developed by Corning partly solved this problem.

Some preliminary experimental work to determine the delays associated with magnetic domain wall motions was conducted. Use of the theoretical torque model evolved earlier in the program was the basis for these experiments.

Servomechanisms Progress Report No. 10, dtd May 1960.

The first configuration considerations involved a 3200-bit continuous strip deposited on an 8 × 8-inch glass plate. For ease of test and analysis the drive windings were deposited upon a companion plate and the two were pressed together during the tests.

Inability to properly orient the easy axis for all domains prevented use of this configuration. Investigations of a technique for curved strip layout then had to be solved before lengthy memory planes could be constructed. This technique was also a necessity if the stepping strips were to perform logical operations; probably the most significant concept for future application. This problem persisted until the termination of Servomechanisms at the recent conclusion of the prime contract.

To insure a computer feasibility model, short linear 20 bit strips were designed that would confirm the stepping strip concept. Six strips were to be made for Litton's use. Four of the six memory loops have worked individually and two loops have circulated information continuously. Noise and intercoupling problems have accounted for the majority of failures. In order that deposition problems of placing the clock windings directly on the magnetic films could be by-passed, the original scheme with the deposition of films on one substrate and the clock windings on another was used. The bonding of the two, face to face, proved inadequate. Loss of signal in some cases and build-up of noise in others has been determined to have been caused by this attachment technique. A new method utilizing epoxy to make a more permanent bond has been successful on one new unit. Another failure was attributed to an open vacuum deposited read loop, and another to an unexplained pinhole in the film that occurred sometime during operation. A nucleation or build-up of an unwanted magnetic dipole at this point contributed noise and loss of primary signal. The budget situation forced an austere spares program where units were secured only upon failure of prime components. This obviously created a longer time cycle between failure and resumption of operation. An investigation revealed that the magnetic field generated by the current pulse in the clock windings was being sensed by the small loop formed at the termination of the shielded conductor where it was soldered to the deposited readout leads at the edge of the substrate. A survey of this magnetic field indicated that moving the magnetic film down to one end of the substrate and having the readout leads terminate at the other end would place the unavoidable loop of the shielded cable far enough away from the magnetic film read-out area. New films were deposited in this geometry and were checked out for the complete operation of write-in, stepping and read-out.

A modest effort was initiated on the deposition of thin magnetic films and clock windings reduced in size 10 to 1 compared to the initial film geometry. These films would exhibit a domain size of only .002 in. The initial results were not satisfactory because of shorts found across the very narrow gap between the clock conductors. The readout loop configurations, at first, encountered severe difficulties in terms of signal-to-noise levels. These loops are necessarily in close contact with the clock windings and with pulse currents of the order of 200 milliamps operating, severe voltage pulses were picked up by the readout loops, com-

Servomechanisms Progress Report No. 10, dtd May 1960.

The first configuration considerations involved a 3200-bit continuous strip deposited on an 8 × 8-inch glass plate. For ease of test and analysis the drive windings were deposited upon a companion plate and the two were pressed together during the tests.

Inability to properly orient the easy axis for all domains prevented use of this configuration. Investigations of a technique for curved strip layout then had to be solved before lengthy memory planes could be constructed. This technique was also a necessity if the stepping strips were to perform logical operations; probably the most significant concept for future application. This problem persisted until the termination of Servomechanisms at the recent conclusion of the prime contract.

To insure a computer feasibility model, short linear 20 bit strips were designed that would confirm the stepping strip concept. Six strips were to be made for Litton's use. Four of the six memory loops have worked individually and two loops have circulated information continuously. Noise and intercoupling problems have accounted for the majority of failures. In order that deposition problems of placing the clock windings directly on the magnetic films could be by-passed, the original scheme with the deposition of films on one substrate and the clock windings on another was used. The bonding of the two, face to face, proved inadequate. Loss of signal in some cases and build-up of noise in others has been determined to have been caused by this attachment technique. A new method utilizing epoxy to make a more permanent bond has been successful on one new unit. Another failure was attributed to an open vacuum deposited read loop, and another to an unexplained pinhole in the film that occurred sometime during operation. A nucleation or build-up of an unwanted magnetic dipole at this point contributed noise and loss of primary signal. The budget situation forced an austere spares program where units were secured only upon failure of prime components. This obviously created a longer time cycle between failure and resumption of operation. An investigation revealed that the magnetic field generated by the current pulse in the clock windings was being sensed by the small loop formed at the termination of the shielded conductor where it was soldered to the deposited readout leads at the edge of the substrate. A survey of this magnetic field indicated that moving the magnetic film down to one end of the substrate and having the readout leads terminate at the other end would place the unavoidable loop of the shielded cable far enough away from the magnetic film read-out area. New films were deposited in this geometry and were checked out for the complete operation of write-in, stepping and read-out.

A modest effort was initiated on the deposition of thin magnetic films and clock windings reduced in size 10 to 1 compared to the initial film geometry. These films would exhibit a domain size of only .002 in. The initial results were not satisfactory because of shorts found across the very narrow gap between the clock conductors. The readout loop configurations, at first, encountered severe difficulties in terms of signal-to-noise levels. These loops are necessarily in close contact with the clock windings and with pulse currents of the order of 200 milliamps operating, severe voltage pulses were picked up by the readout loops, com-

pletely masking the desired readout signal. After an intense investigation it was found that specific readout loop geometry, in conjunction with a critical location with respect to the clock windings, reduced the noise pickup to zero. With current stepping strips, readout voltages of around 8 millivolts are now being obtained.

The delivery of short magnetic thin film stepping registers was completed with the delivery of 8 stepping strips and drive wiring to Litton Industries for installation in the feasibility arithmetic breadboard computer. Successful completion of this computer would have demonstrated feasibility of 3 significant research achievements of ANIP. First, the development of continuous magnetic thin film memory by Servomechanisms, Inc., second, the development of high performance thin film microcircuits for typical computer applications by Varo Mfg., and third, the integration of the first two in a basic arithmetic computation system breadboard by Litton Industries. Drive wiring for the computer stepping strips was accomplished by means of separate 2-phase drive boards made by conventional etching techniques. A single-phase thin film drive wire was made by vacuum deposition but was found to have high resistance—about 25 ohms for a 24-bit stepping strip. More research will be necessary to reduce the resistance or utilize higher impedance drive lines.

Utilizing deposited windings to provide the magnetic field to orient the easy axis during vacuum deposition was tried but, because of cracks in the substrate or dielectric, this effort was not successful. The configuration of their flip-flop package was slightly different and of less volume than that of Varo. This brought the internal heating problem back into the picture, although the overall performance had been good. A redesign was suggested because of changes in electrical and thermal characteristics of the chip transistors first pioneered with Fairchild. The design goal was better reliability—to allow completion of the demonstration and feasibility program.

The conclusions drawn at this stage are certainly not to the detriment of either the stepping strip concept or the field of microelectronics, but rather point up the problems of proving tomorrow's concepts with today's state of the art. The thin magnetic memory has worked well independently of the computer breadboard application and microcircuits are indeed being successfully applied in other systems. However, in both cases the understanding of the phenomena of both these concepts and the most effective means for their production will require a great deal more research.

The development of simple linear strips analogous to drum computer channels and unit packaging of thin film microcircuits with lay-on, chip-type active elements for use in the near future can be considered as an application worthy of consideration. Performance knowledge is available on the basic elements required for contemporary application. Since the attachment situation is still questionable, a parallel, well instrumented test program is necessary. The availability of lower power active elements would provide a newly designed system having considerable performance advantage over the circuits in the current breadboard. Present knowledge of redundant circuit techniques could be applied to obtain the desired reliability.

Servomechanisms, Inc. Technical Report 62-1 "Magnetic Films Survey," dtd December 1961.

Items deserving of future research in this same vein include: integrated circuits with deposited active elements; low-power circuits; multiple packaging techniques; and techniques of built-in redundancy in machine organization to improve reliability. Specifically in the thin film area the following research is recommended: dynamics of magnetic wall movement; utilization of domain rotation phenomena to increase data rate; experimental studies with longer closed stepping strip circuits; and studies in the use of strips to perform logical operations. These areas were outside the funded program as established for the last year.

Douglas Specification 7668677 "Microcircuitry Development of Materials and Techniques," dtd August 1957.

While work was continuing at Varo on the basic computer microcircuits, and at Servomechanisms on the magnetics of stepping registers, the need for a better understanding of the basic materials being used in the research became more apparent. Problems of stable resistance films and substrate materials with a minimum of defects had already appeared at Varo. In addition, the energy transfer concept of material for electronic system needed further exploration. A Douglas specification defined these two objectives: 1) Determine the basic electrical transfer properties of materials (initially inorganic); and, 2) Apply vacuum deposition technology to the development of complete circuit functions. Upon evaluation of the proposals, the Servomechanisms Research facility at Santa Barbara, California, was selected to conduct an investigation of these areas.

This particular program was limited to the investigation of the electrical properties of refractory inorganic compounds. Although mechanical properties occasionally became important, the largest effort was directed toward electrical phenomena such as resistance, capacitance and semiconduction. The field of refractory compounds was selected because of the increasing temperature requirements of practical applications.

Servomechanisms, Inc. Progress Report No. 1, dtd February 1958.

It became apparent that there are a huge number of permutations of elements to form compounds, possibly something in the order of 10^{-6}, considering binary and ternary combinations. There is, in addition to this, the class of non-stoichiometric compounds which have been extensively explored by the Servomechanisms, Inc. Research Laboratory.

Servomechanisms, Inc. Progress Report No. 2, dtd May 1958.

Typical of this type compound is the sub-oxide family. For example, it is possible to selectively remove oxygen from many oxides such as TiO_2, and form other compounds. This results in such compounds as TiO_3, TiO, $TiO_{1.78}$, $TiO_{1.86}$, and $TiO_{1.999}$. Each has specific electrical properties and there are thus limitless possibilities of new variations of element combinations. This almost completely rules out the simple cut and try approach to find particular properties that one might desire in a compound. Therefore, the approach in the materials research program was to accumulate as many as possible of the rules and relationships that could narrow down the field in determining optimum compounds for the purpose desired. The end

goal is the attempt to design a compound for a specific application. This effort included literature correlation of known data as well as experimental measurement work and theoretical considerations utilizing the rules of solid state physics such as the quantum mechanic band theory.

Materials research work of the nature undertaken, was a most difficult field of endeavor. For example, the purity problem is one of extreme importance. This can be seen by simple arithmetic. A typical solid material has in the order of 10^{22} atoms per cubic centimeter. In many cases, it is difficult or impossible to purchase the material with impurity content less than .001%. Such material, although it would be considered of quite high purity, has about 10^{17} impurity atoms per cubic centimeter, which is quite a staggering number. In general, purities of 99.99999% are required for serious work in this field.

Microcircuitry is dependent on the utilization of electrical or magnetic phenomena in solid materials to produce the effect to be utilized rather than creating standard electronic circuits with various components to accomplish these ends.

Servomechanisms, Inc. Progress Report No. 7, dtd August 1959.

A portion of the materials research work has been done in support of microminiaturization. For example, the problem of evaporated resistive films has been studied. Although nichrome is used extensively for the purpose, difficulties arise in obtaining stable films for high values of resistance such as one megohm or more. This results from the fact that nichrome films must be made extremely thin to obtain compact resistors with high ohms per square values.

A dielectric investigation program was then conducted to examine the possibilities of thin film dielectrics for use as capacitors at elevated temperatures. It was found that aluminum oxide, ceric oxide and silicon monoxide and dioxide yield thin dielectric films with good properties up to 350°C.

Servomechanisms, Inc. Progress Report No. 1, dtd February 1958.

Early in the program, a large part of the refractory semiconductor effort was directed to the problem of thermoelectric energy conversion. This effort was the result of a combination of problems for which the thermoelectric approach appeared to be a solution. The first was the heating problem within microcircuits. A solution for reclamation of this waste heat was a simultaneous maintenance of an acceptable temperature level within the circuits. The second effort was reclamation of larger quantities of exhaust heat from primary power engines for use as an auxiliary power source for the system.

Thermoelectric, as the name indicates, refers to an inherent characteristic relating heat and electrical energy. Simply stated, materials exhibiting thermoelectric properties may be heated to generate an electrical potential or energized electrically to produce a thermal potential. Thus in a thermoelectric device consisting of two rods of dissimilar materials connected at each end, electrical current is generated by heating one junction and cooling the other.

The study of thermoelectric materials therefore centers around the understanding and control of the following three factors:

1. Electrical conductivity, which is a function of the number of the carriers and their mobility.
2. Thermal conductivity, which is more complex and depends primarily on two basic mechanisms. One involves the same conduction band electrons that contribute to electrical conductivity. As these electrons flow through the material, they transfer thermal energy – one component of heat conduction – which is, in turn, dependent on the number of electrons and their mobility. A second mechanism of heat conduction is known as phonon conduction. This consists of heat transfer due to thermal excitation of crystal lattice vibration in the material which is quantized to define energy units called phonons. These travel through the crystal lattice, transporting heat and contributing to thermal conduction.
3. The thermoelectric potential or Seebeck coefficient is the electrical voltage generated at the junction under the influence of a thermal gradient expressed in microvolts per °C. temperature difference between hot and cold junctions. It is an inverse function of the concentration of carriers in the material.

A relationship of these three factors which expresses a figure of merit for a material has been introduced by Ioffe in the Russian literature and is used extensively in the field. This figure of merit, Z, is given by

$$Z = \frac{S^2 \sigma}{K} \tag{1}$$

where

S = thermoelectric potential

σ = electrical conductivity

K = thermal conductivity

Obviously then, a good thermoelectric material would be one in which S and σ are large and K is small. Unfortunately, the relationships of these factors are such that this is not readily achieved. The plots of Figure 1 aptly demonstrate these relationships for three general classes of materials. Significantly, values of Z are greatest for semiconductors.

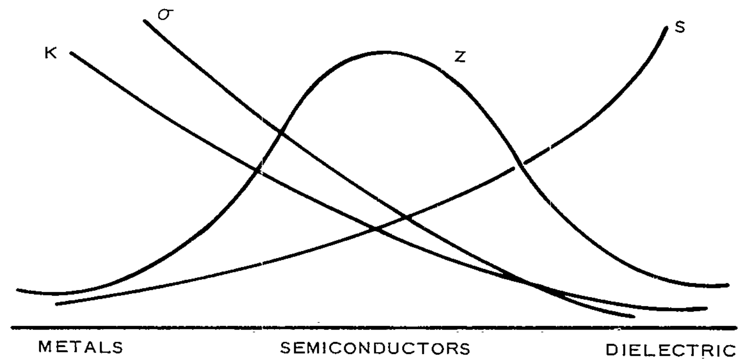


FIGURE 1. RELATIONSHIP OF THERMOELECTRIC PARAMETERS TO TYPE OF MATERIAL (FROM REDEMSKE)

In addition, a thermoelectric generator is basically a heat engine and as such its conversion efficiency is given by the Carnot cycle efficiency,

$$\eta = \frac{T_h - T_e}{T_h} \qquad (2)$$

Accordingly, two avenues appear for direction of research:

(1) Increase the Z value of conventional semiconductors.

(2) Develop semiconductive materials capable of retaining their properties at higher temperatures (e.g., 1000°C), thus leading to higher conversion efficiencies.

Since the first of these did not appear promising, the decision was made to pursue the second approach. Thus the ANIP-sponsored thermoelectric power generation program at Servomechanisms began quite modestly in the materials research phase. Nevertheless, in the relatively short time (less than two years) that it was allowed to continue, it proceeded to the brink of success in the equipment phase.

Although ANIP support was withdrawn before successful equipment could be developed, the program was continued under BuShips sponsorship with gratifying results. At the conclusion of the ANIP-sponsored

Servomechanisms, Inc. Progress Report No. 3, dtd August 1958.

work, techniques still had not been developed which would assure the structural integrity of the thermoelectric generator. Since that time these problems have been solved, and production of 250-watt, shelf-item units suitable for space flight is now considered feasible. Highlights of the work accomplished by Servomechanisms under Douglas cognizance are listed below:

Servomechanisms, Inc., having been engaged in materials research for some time under Air Force sponsorship, proposed a similar type of study for the Office of Naval Research in May 1957 to cover the proposed program. The program at that time provided for a study of insulators, conductors, semiconductors, and nonlinear effects to arrive at new materials capable of retaining desired electrical properties at elevated temperatures and suitable for deposition by vacuum evaporation, vapor plating, or other techniques.

Servomechanisms, Inc. Progress Report No. 3, dtd August 1958.

This early work in materials included a considerable amount of investigation of thermoelectric material phenomena. As more knowledge was gained, the scope of the effort was extended to include studies of thermoelectric energy conversion methods. By June 1958 a small thermoelectric generator capable of delivering 10 amperes at ¼ volt, with 6% to 7% efficiency, had been constructed. However the hot junction temperature was only 150°C with a cold junction temperature of 30°C, and the next step was seen as a hot junction temperature of 1100°C. It was hoped to generate 10 amps at 1½ volts with this demonstrator unit.

Problems (usually forming and fabrication induced fractures in the research materials) continued to plague the program until December 1958 at which time the small generator was completed and operated satisfactorily. Upon completion of the 10 amp/1½ volt generator, work commenced on a 250-watt generator. Forming and fabrication problems were again encountered and funding limitations necessitated termination of the effort at this point.

Servomechanisms, Inc. Progress Report No. 5, dtd February 1959.

One of the earliest and most challenging display concepts evolved under the ANIP is that of the contact analog. It was always the goal of ANIP to develop a contact analog display which could be electronically generated in the windscreen area. With such a display superimposed over the real world, transition between instrument and visual flight conditions would not require the pilot to alter either his reference system or his visual focal point. Obviously, such a "see through" display would be feasible only if a transparent phosphor could be developed for the display screen. Kaiser Electronics had made significant progress on developing the flat picture tube. Little progress had been made in the area of transparent cathodoluminescent phosphor despite the promise which previous investigations had indicated. Thus Douglas directed Servomechanisms to initiate an investigation of transparent phosphors in November, 1958.

Servomechanisms, Inc. Research Technical Report, "Transparent Luminescent Films – I," dtd September 1959.

By April 1959 all necessary equipment had been assembled and the program was progressing satisfactorily. Zinc silicate films were being deposited and test equipment for electron beam phosphor excitation was in operation.

Servomechanisms, Inc. Research Technical Report, "Transparent Luminescent Films — II," dtd January 1960.

Transparent phosphor films were deposited which have an output of 45 foot-lamberts at 10 kilovolts with a current of 1 microampere per square centimeter. This brilliance compared favorably with any phosphors which were then available. Transparency was in excess of 85%. At this point samples were left with Kaiser Electronics for test purposes. Termination of the Kaiser flat cathode ray tube program prevented a thorough analysis of these samples.

The interest by ANIP and Kaiser in a two-dimensional solid state display medium transferred the interest from transparent cathodoluminescent (electron bombardment) phosphors to the less understood electroluminescent phosphors. The original phosphor work is still of value. To conventional cathode ray tubes (television, oscilloscope, etc.), the transparent phosphor is of advantage when relatively high ambient light conditions prevail. The unexcited phosphor will transmit the light falling on the tube face while the illuminated portions will reflect the light, enhancing the apparent contrast.

Kaiser Technical Report "Determination of EL Phosphor Requirements," dtd September 1961.

As progress was made at Kaiser on the techniques for generation of a solid state display device, the requirements for the light transducing material were established. Kaiser began some exploratory work on electroluminescent (EL) phosphors and were able to increase the performance substantially. The Kaiser method of switching the elements of the display matrix required that the EL material respond to 50 to 200 volt pulses with nanosecond duration and 13 MC pulse repetition rates. It had been assumed by earlier investigators that EL materials would not respond to pulses or CW frequencies much above one kilocycle. Kaiser was able to produce low but visible light outputs up to 0.1 foot-lambert.

Additional effort beyond that available at Kaiser was necessary to improve the EL phosphors. Servomechanisms was brought into the picture again to capitalize on the previous work in phosphors and to investigate achievements reported by other researchers on the superiority of thin film deposits of EL materials. The bulk of the experimental effort devoted to the study of EL during the past decade had been accomplished with powdered phosphors suspended in some dielectric material. Because analysis of such composites was somewhat inexact, an understanding of the phenomena of EL was incomplete. A small amount of work on single crystal phosphors had yielded substantially greater information. Based upon an earlier success at SMI in fabricating an EL cell by vacuum deposition techniques, work on producing single crystal thin phosphor films was begun.

Servomechanisms, Inc. Technical Report 62-3 "Electroluminescent Thin Films," dtd January 1962.

Requirements for electroluminescent materials as a result of the solid state display requirements established by efforts at Kaiser Electronics were determined in meetings between Kaiser and representatives from Servomechanisms, Inc. and Douglas Aircraft. Increased brightness and reduced electrical capacitance were desired characteristics. It has been observed that light emanates from only one surface of the crystals in powdered electroluminescent materials. In an attampt to increase the light output, a thin film sandwich of tin oxide (conductor), zinc sulphide doped with manganese (phosphor), germanium dioxide (dielectric), zinc sulphide (phosphor), aluminum or molybdenum (conductor) was deposited on a glass substrate. The dielectric material thickness was increased by approximately 150 times to decrease the cell capacity. Dielectric leakage was reduced from a few microamperes at

15 volts to unmeasurable quantities at 180 volts. Although the objective of reduced capacity (and higher dielectric strength) was attained, there was no light output. It is conjectured that some leakage current must be necessary or that the doping was insufficient.

A procedure was developed for producing an electroluminescent thin film of manganese-activated zinc sulfide by a one-step process of coevaporation of a mixture of ZnS and Mn metal powder.

Germanium dioxide was found to be a satisfactory dielectric layer compatible with the phosphor. Silicon monoxide, on the other hand, was found to be incompatible with the phosphor.

Evaporated aluminum and molybdenum were determined to be satisfactory for the top electrodes. Molybdenum offered an optical advantage in that a film which was semi-transparent in the visible range could be used.

A d-c bias superimposed on a pulsed signal was observed first to decrease the emission intensity of the thin film electroluminescence, then, after a certain threshold value had been reached, to increase the emission intensity through an ac-dc enhancement effect.

By a detailed study of the variables involved in the vapor deposition process, a reproducible procedure was established for production of a ZnS:Mn thin film electroluminescent cell configuration. This procedure is a simple one-step deposition process which does not require excessively high temperatures or any succeeding heat treatment.

Considerable advancement in the control of the deposition and substrate preparation, including the bottom electrode, led directly to the fabrication of successful arrays of small cells, each approximately 0.000625 $inch^2$ in area.

A correlation was indicated between strong electroluminescence and the development of a well crystallized, highly oriented film structure. The cubic form of ZnS was consistently observed in the best films as compared with the hexagonal form reported by others.

Exceptionally high dielectric strength (2500 volts/mil) and effective dielectric constant (50 to 70) were discovered in cells containing an additional dielectric layer of GeO_2. The dielectric constant of ZnS:Mn films alone was found to be about 20, twice as great as that reported for undoped ZnS films of the same thickness.

The rate of change of light output of the thin film electroluminescent cells per incremental change in applied voltage was observed to be significantly greater than that for a common commercial electroluminescent cell.

Because of the emphasis put on the study of the deposition process and the structure of the films, various modes of excitation, e.g., pulse excitation, were not examined as was originally anticipated.

Servomechanisms, Inc. Report 62-7 "Electroluminescent Phosphor Research," dtd December 1962.

A novel discovery made during the course of the research was that unique hollow crystals of hexagonal ZnS develop under particular heat treatment conditions.

Probably the most basic of all materials efforts was a short study by SMI.

Servomechanisms, Inc. Report 62-4 "A Selection of Physical Effects and Their Implications in Recent Materials Research," dtd October 1962.

The object of the materials effort was to determine the basic transfer characteristics of classes of material so that they might contribute to the energy transduction requirements of future systems. The entire system from the sensed environment to the interface at the human operator is primarily a sequence of energy conversions and manipulations that for convenience have been categorized as sensors, data processors and displays. Before systems can be thought of in these terms, knowledge as to the energy transfer functions of basic building blocks of materials that form these systems must be determined. The Servomechanisms research team was directed to investigate this broad area.

Servomechanisms, Inc. Report 62-5 "Appendix: A Selection of Physical Effects and Their Description," dtd November 1962.

The study of fundamental material properties has progressed through the delineation of some eighty common and uncommon effects that have been observed in materials. In these effects, as typified by the Kerr Magneto-Optical effect, the Mossbauer effect, the Zeeman and Stark effects, etc., the materials act like an operator or transfer function. It can be shown in most cases that the signal operated upon is either electromagnetic radiation, magnetic fields, mechanical forces or temperature. A classification of these effects on the basis of the type of input signal, control, and output signal has been made to aid in the determination of those properties common to the various classes of effects.

Considering these effects as operators on different "signals," showed that they could be classified by the rank of the tensor describing the operator and also in a qualitative way by the input, output, and control signals that were involved in the effect. The firm conviction is held by the members of the ANIP team involved in this effort that with the proper theoretical and experimental program a methodology will be evolved for generating materials to operate directly on the varying types of information sensed by man-machine systems and to process these data in their natural form rather than translate or transduce them all into a common "language" or signal type as is currently done.

Organization has been in order of complexity. Fields are considered "environments" and radiation particles and vibrations are considered "inputs" or controls. A simple effect such as "electroluminescence" would be evidenced by one material such as zinc sulphide (doped with copper or manganese) one input such as an "electric field or current" and one output such as "visible light radiation." A more complex effect would be the "Hall" effect on one material, two environments such as "temperature" and "magnetic field," one input such as an "electric current," and one output such as a "voltage." This classification is expected to be the key to new research. Application of this classification is the starting place for possible new devices. Already the effect of dichroism, wherein a light beam is made to change its direction through a crystalling substance by means of another light beam, has found a possible application.

SIMULATION AND TEST

A familiar Chinese proverb states that "a picture is worth 10,000 words." This may be true, and static, pictorial displays of the ANIP concept have proven to be a very useful means of communication with the uninitiated. However, it was felt that a dynamic display of the ANIP concepts would be worth at least the next order of magnitude of words, both for communication purposes and for experimental verification of the theory. It was, in fact, mandatory for the latter, both for qualitative analysis of the validity of the concept, and for quantitative data that would ultimately provide the necessary data for production equipment specifications.

Accordingly, a simulation effort was initiated early in the program; so early, in fact, that many of the requirements had not yet been clearly defined, nor had the methodology been developed for meeting many of those that were defined. Basic to a dynamic display-control system was a device that would react to control inputs in a manner that faithfully reproduced the dynamic reactions of an airplane. For this requirement, a C-11B Link trainer, which simulated the dynamics of the USAF T-33 aircraft, was obtained in 1954.

A mock-up of the model A4D aircraft cockpit was also obtained to serve as an operating mock-up of the ANIP concept. Modification of the A4D cockpit to the ANIP configuration included complete removal of all A4D controls and instrumentation, with the exception of the throttle. A side stick flight control, and the initial vertical and horizontal ANIP displays together with their controls, were substituted. Pilot inputs to the flight and throttle controls were fed directly to the C-11B as though they originated at the C-11B controls. The resultant dynamic outputs of the C-11B were sensed and fed as inputs to the contact analog ground plane generator. This was a dynamic optical display that was observed by a vidicon and reproduced on a CRT in the ANIP cockpit where it served as the vertical contact analog display.

The ground plane generator included a programmed command flight path (on the ground plane) which was matched as nearly as possible by a pathway painted on the face of a second CRT. This CRT was used for the horizontal situation display in the ANIP cockpit. An aircraft symbol, mechanically driven in orientation and location by the heading and map plotting outputs of the C-11B, was viewed by a vidicon and displayed on this tube. While this dynamic representation of the ANIP concept was useful as a demonstration device, the poor performance precision of this system precluded precise experimental work. Most of the inadequacies were due to problems of a mechanical nature such as the servo response rates required in driving relatively large masses (vidicons and optical prisms) with a high degree of accuracy and repeatability.

As the state of the art was advanced, this heterogeneous combination of optical, mechanical, and electronic subsystems was modified to include more sophisticated elements as they became available.

Good flight simulation of even low performance aircraft is an expensive and time-consuming task and requires equipment capable of providing the proprioceptive and visual motion cues; i.e., a moving platform simulator. In 1955, such a device was not available to the ANIP, yet some equipment and concept demonstration was desirable. Equipment had been developed to the point that made it possible to demonstrate that the basic information display concept of the ANIP (providing information via real-world cues in an integrated form) was feasible and to obtain some qualitative evaluation of the superiority of the display for spatial orientation over "conventional" numeric gage-type displays.

Douglas Specification 7554941, "Integrated Instrument Test Vehicle," dtd January 1956.

To circumvent the moving simulation and demonstration problem, an aircraft was made available to the coordinator for installation of equipment and demonstration.

The aircraft was a T2V-1 airplane which is the later Navy version of the Air Force T-33 two-place trainer. This was designated Research Vehicle No. 1 (RV-1) in keeping with the systems analysis identification that was associated with the preceding studies. A series of these research vehicles was envisioned throughout the remainder of the program.

Following Douglas preliminary design objective, the aircraft manufacturer modified the aircraft as necessary. Douglas installed extensive flight data gathering and recording equipments for checking out a transparent flat television tube, display generator, navigation display and central computer developed under separate ANIP research programs.

Douglas Testing Division Report DEV-2455, "IID Program Final Report," dtd August 1959.

The aircraft was flown sufficiently to demonstrate principles and permit the qualitative evaluation of the equipment. The basic results indicated the information display was superior for aircraft. Spatial orientation was much more easily maintained and vertigo practically eliminated. Training for instrument flight reference was much easier. The first step in the program goal of virtually uninhibited all-weather flight had been achieved. Because the RV-1 system was basically a laboratory breadboard, the reliability of the demonstration airplane diminished and its maintenance cost became excessive. After the general feasibility ot the principle was demonstrated in flight, it was believed that more basic research in the laboratory would produce more useful information. The airplane was therefore returned in 1959 to the operational activities of the Navy and laboratory simulation, though limited, was used for the remainder of the program.

In 1959 the equations of motion of the model A4D aircraft, processed by an analog computer (REAC), were substituted for C-11B inputs to provide the dynamics of an operational aircraft in the Douglas laboratory.

These were used as inputs to the optical display equipment and to a new electronic flight path generator manufactured by Kaiser Aircraft & Electronics. The optical display showed the ground plane and the horizon, giving pitch, roll, and heading inputs which were video-mixed with the Kaiser flight path display to produce the ANIP contact analog display. The essential improvements provided by these modifications

were (1) confidence in the validity of the aircraft dynamics; (2) repeatability; and (3) demonstration of ANIP concept in a high performance aircraft.

The Kaiser flight path had certain limitations inherent in its design. Perspective was lacking between the pathway edges in that the crossbars remained orthogonal to the centerline and were of equidistant separation from apex to base. A smooth altitude traverse of the pathway could not be made; i.e., the display would flip from "near above" to "near below," and vice versa, without a smooth transition. The pathway boundaries lost their mathematical fidelity when outside a near-null position. However, this display was truly an advance in that it was electronically generated and that flight could be conducted below as well as above it.

The horizontal display was also advanced by the electronic generation and video mixing of a command flight path, a moving aircraft symbol, and a variable fuel range circle. The motion of the aircraft symbol, however, was still governed by X, Y, and ϕ (lateral, longitudinal and directional) inputs from the flight simulation equipment. This display was developed in the Douglas Aircraft laboratory.

Douglas Report LB 31018, "ANIP Laboratory Simulator," dtd August 1962.

Next, in 1961, came two major improvements that were integrated simultaneously. One was a new flight path generator, developed by General Electric, that had much greater mathematical fidelity and more flexibility, and the other was a map plotter and symbol generator combination developed by the Avion Division of ACF Industries, which added flexibility to the horizontal display.

As noted in the human factors review above, the basic premise of the contact analog concept was that it was believed essential that a geometrically faithful replication of the real world be provided by the display generation equipment if the pilot were to do as well under instrument as he could do under contact flight conditions. This requirement provided a baseline for the design requirement of the display generation equipment as regards mathematical or geometric fidelity.

The GE flight path consisted of 32 circles that became elliptical in perspective. The eccentricity of these ellipses reached unity as an altitude traverse of the pathway was made, thus giving a smooth transition from above to below, and vice versa. The pathway centerline could be curved, and the major axes of the ellipses could be "banked." Here a limitation was that these axes remained mutually parallel and thus a transition from a straight to a curved flight path could not be generated.

The map plotter consisted of two superimposed transparent glass slides, one of which portrayed an aeronautical map and could be moved in the N-S and E-W directions. The other, portraying the aircraft symbol, could also be moved in the N-S and E-W directions, but additionally, it could be rotated in heading. These slides were viewed simultaneously by a vidicon. Their separate drives allowed a map moving under a symbol that was stationary except that it could rotate in heading. These motion inputs again came from the simulation equipment. Display slew controls were added to the cockpit for pilot control of the map area to be viewed.

Command courses were programmed into the horizontal display by means of an acquisition circle controller, mounted on the throttle, and acting through the symbol generator and its attendant computer. The symbols were displayed on a CRT and were video-mixed with the map plotter display. A command course was programmed by moving the acquisition circle until it coincided with the desired destination shown on the map, followed by actuation of the "course reset" control. This caused a course line to be drawn from the present position to the destination. This geographic track was retained despite subsequent relative movement of the aircraft symbol until the destination was reached, or a new destination was programmed. In the latter case, the old track was erased and the new one was displayed.

Douglas Film No. 806, "A4D ANIP Flight Simulator."

Equipment as complex as this required almost continuous maintenance and calibration work and it was found that quite often it was inoperative when the need for its use in demonstration arose. Work on improvement modifications also kept it out of commission for extended periods. If there was enough advance notice and the need for demonstration was deemed imperative, the modification work was interrupted long enough to return the demonstrator to operating condition. This situation was highly uneconomical in both time and money and therefore a motion picture fully describing the demonstrator and showing the actual displays in action, was made. This allowed uninterrupted evaluation and modification work and allowed for wide dissemination of the ANIP display concept in a brief, but readily understandable form.

The next step, in 1962, was to eliminate the need for the optical display generator and two of the vidicons. General Electric furnished a textured ground plane, moving in true perspective, that was generated entirely by a digital computer. This was displayed both in black and white and in full color. This simulator was capable of displaying changes in altitude, pitch and heading when first installed. Roll display capability was added to the black and white display by Douglas through mechanical rotation of the yoke on the output cathode ray tube. This simple method, however, could not be applied to the color display, due to the nonconcentricity of the three electron guns involved. Electronic rotation of the color display was proposed, and was considered feasible, but the funds required for such work were not made available. Consequently, the color display served mainly to demonstrate the potential of simulating the real world within the cockpit.

Some human factors studies were initiated in an effort to establish the amount of superiority of a color display over a black and white display but termination of the Douglas contract halted the project. It was also proposed that the GE flight path display be integrated with the roll-capable, black and white, GE ground plane display to furnish a complete, electronically generated, ANIP contact analog. It was expected that this display, together with the improved map display, would provide the ANIP simulator with a system of sufficient accuracy and mathematical fidelity and flexibility to allow a quantitative comparison between the ANIP and conventional displays. With these tools, Douglas could assign limits to the display requirements and provide the data necessary for production-type display and equipment. The equipment built and supplied by General Electric was intended to be used only in the laboratory. It was not packaged or designed for flight use. It was a very versatile and flexible laboratory tool with which many parameters of the ANIP displays could be studied. One of the prime objectives of the evaluation program was to establish the essential and secondary information requirements of the display. This knowledge would permit a procuring agency to specify equipment which was adequate but of minimum complexity.

Evaluation of the display generated by the General Electric built equipment had just started when the ANIP effort was terminated at the direction of the Office of Naval Research. The equipment was returned to the General Electric Company for modification to provide more capability by inclusion of aircraft roll equations and curved flight computation, addition of a speed indicator ribbon and other information. This modification is presently being made under contract with the Office of Naval Research.

ADMINISTRATION

The term "administration" for the fixed-wing phase of the Army-Navy Instrumentation program, as used in this report may be defined as the summation of those activities which were not specifically directed to detailed studies ending in reports, or to specific programs but for which the coordinator, Douglas Aircraft Company, was responsible. This included such items as simulation and test, systems analysis, and the preparation of specifications for subcontract work.

Under the Administration heading are grouped such activities as the coordination between Douglas and coordinators of other programs similar to ANIP, between all of the subcontractors, and between the subcontractors and the Navy, studies of the state of the art, dissemination of information related to and generated by the program, and similar administrative details as directed by the Scientific Officer and the Joint Working Group.

Douglas Report No. 40641A, "ANIP Historical Report," dtd September 1962.

The overall administration of the fixed-wing phase of ANIP has continually been under the direction of the Joint Working Group made up of members of the Army, the Bureau of Naval Weapons (originally the Bureau of Aeronautics) and the Office of Naval Research. Chairmanship of this group rotates annually among the members. The ANIP Scientific Officer from the Office of Naval Research is the permanent executive who administers all directives of the Working Group. The prime contracts are issued by ONR.

While the basic ONR contract for the coordinator has rather loosely defined the duties of the coordinating contractor for the fixed-wing program, contractor activities have been tightly controlled by the Working Group through the Scientific and Contracting officers of the Office of Naval Research via the directives and contract amendments.

The administrative phase of the program may be broken down into three areas: Planning, information gathering and dissemination, and coordination of the overall program.

The program required careful overall planning in order that duplication of research and development could be minimized and in order that priority could be meanfully assigned to the tasks undertaken. Planning for each period of activity or funding was based on objectives established by analyses of the requirements to achieve the long range program goals. Tasks or projects were originated to fill gaps in knowledge and/or techniques and equipment. After the plans had been drawn up, the Scientific Officer made presentations to the Working Group and the cognizant ONR, BuWeps and Army Administrators who usually devised minor modifications to the plan. The Scientific Officer, personally responsible for the planning and presentation activities, was assisted by the coordinator with information, art work, brochures and personnel for direct assistance as requested.

Concomitant with finalization of plans for each period or phase of the program, the coordinator released to industry specifications for approved projects; evaluated proposals; recommended acceptable subcontractor proposals to the Navy; negotiated the approved subcontracts; monitored the work; evaluated the results and reported to the Navy with respect to the current and future potential of the work.

To plan the Army-Navy Instrumentation Program (or the Integrated Instrument Program as it was originally known) intelligently, the coordinator and the Office of Naval Research needed to know the state of the art. Industry wanted to know how best to participate in the program in order that ideas could be generated and offered as solutions or as fruitful areas of research on the problems generated by the program. To fulfill these needs two basic activities were initiated. The first activity was the dissemination of information about the program. This was initiated by a conference in Washington, D.C., April 9, 1953, to brief military and civil government agencies and industry on the Integrated Instrument Development Program. Such planning as had been done up to this time was preliminary and was based on earlier work done under ONR sponsorship.

The Navy announced initiation of the program, explained its goals, and introduced the Douglas Aircraft Company as the program coordinator for industry. Aids in the conference were a brochure and cockpit mockup prepared by Douglas under a preliminary study contract.

Conferences and industry briefings on the program needs and results continued on both a formal and informal basis. Informal presentations were made to industry representatives at their request. For two years the Douglas Company made presentations at least once a week at El Segundo, California, to accommodate industry requests for information about the program. The Scientific Officer also made many individual presentations, and teams, headed by the Scientific Officer, made several trips to Europe at the request of NATO and SEATO military agencies to brief them on the program.

Formal presentations and briefings (symposia) were conducted in Los Angeles, Dallas, and Fort Worth. For these formal functions, the coordinator aided the sponsoring agency, Navy or Army, by issuing the invitations, making all detail facility arrangements, soliciting papers from subcontractors, and preparing or arranging for all the displays associated with a large gathering of four or five hundred people.

The coordinator produced many aids for the dissemination of information of both the formal and informal meetings. In addition to the mockup and brochure for the first announcement meeting, numerous brochures and several full-scale cockpit and component mockups were made. Poster-type displays were designed and built for the symposia and used extensively later for information purposes. Reports of the formal symposia were compiled, including the papers presented on the projects and progress of the program. These voluminous reports were printed and distributed widely by the coordinators.

Douglas Report ES 17227, "Program for the Presentation of Flight Information," dtd January 1953.

"ANIP Symposium Progress Report," dtd October 1957.

"ANIP Symposium Progress Report," dtd 31 August 1959.

(Bell Document 0228-100-03).

Douglas Report ES 26040, "Integrated Instrument Development," dtd September 1955.

Douglas Report ES 26568, "Pathways in the Sky," April 1957.

Douglas Film No. 516, "Integrated Instrument Development," 1955.

Douglas Film No. 652, "Army-Navy Instrumentation Program," 1957.

Douglas Film No. 806, "A4D ANIP Flight Simulation," 1961.

One of the most effective media has been motion picture films. One hundred copies of the Army-Navy Instrumentation Program Objectives were made and distributed. The last major film, released in 1961, shows the state of development of the two basic displays and major concepts in operation in the Douglas laboratory simulator.

Due to the broad scope of the Army-Navy Instrumentation Program, it provided material for many technical papers written by those who participated actively in the research. These papers were presented not only by the coordinator personnel, but by many of the research organization personnel doing work under the program. Douglas personnel prepared and presented papers on the overall scope of the program, information requirements, medical electronics and simulation developments, and many aspects of the control display interrelationship problems. Many of these reports were printed and distributed by the coordinator in the same manner as brochures relating to the program.

In advance of, and concurrent with, this information transfer to industry was the exchange of information between industry and everyone involved in the Army-Navy Instrumentation Program. This reverse flow of information, in addition to research results, was primarily state-of-the-art information on pertinent problems and new ideas relative to their solutions. To enhance the flow of state-of-the-art knowledge, the Office of Naval Research employed Documentation, Inc. to prepare a limited vocabulary for a newly devised system of information indexing and retrieval. Documentation, Inc. also abstracted and indexed 2500 documents of interest to the program. From 1953 to 1958 Documentation, Inc. worked under the subcontract to Douglas. During this time Documentation, Inc., Douglas, and ONR representatives visited many industrial facilities to disseminate ANIP information, determine the interest of the organization visited, and to evaluate the organization's capability for participation in the program. This information was used in distributing specifications to industry for bids on proposed projects. A carry-on to this procedure was distribution of an area of interest form which any organization could obtain, fill out and forward to the coordinator. Organizations that had submitted area-of-interest survey sheets were placed on the distribution lists for applicable specifications and other pertinent information. During this period, Documentation, Inc. continued the work of abstracting and indexing information.

In 1958 Documentation, Inc. established a Man-Machine Information Center under contract to the Office of Naval Research. Data generated under the ANIP program were forwarded to this Center for indexing and anyone authorized, through interest or participation in the program, could then obtain this information from Documentation, Inc. The request could take the form of a telephone call, a letter, or a telegram. Documentation, Inc. also surveyed the literature and indexed and abstracted a large number of documents generated outside the program — and all this information was also available. The Man-Machine Information Center was a great aid in disseminating technical information and the idea has since been adopted by the National Institute of Health and NASA. The Center did much to enable ANIP to stay abreast of the art and to permit

new programs such as the Submarine Integrated Control Program (SUBIC) and SURIC (for surface ships) to start with up-to-date information not otherwise available.

While the above activities supplied information to industry regarding the objectives and operation and accomplishments of ANIP and supplied the Administrators of the program with knowledge of the state of the art and the capabilities of industry, a great deal of teamwork was required to keep the program operating smoothly and effectively.

In 1955, the rotary-wing phase of the Army-Navy Instrumentation Program was initiated with Bell Helicopter as coordinator. In 1957, the Submarine Integrated Control Program was initiated, followed in 1959 by the Surface Ship Integrated Control Program. Since the fixed-wing and rotary-wing phases of ANIP and the submarine and surface ship programs had the same objectives, close coordination between the various coordinators was required in addition to the coordination between the Navy, subcontractors, and industry as a whole. This entailed much travel and many meetings between the Navy and the subcontractors.

Under the fixed-wing phase, as many as twenty subcontractors were working at one time. This required constant monitoring by the coordinator in order to insure that the subcontract work not only progressed in accordance with the specification and the aims, philosophies and goals of the Army-Navy Instrumentation Program, but also that it dovetailed technologically with the output of other team members. Since the system requirements approach to problems was somewhat new, many of the subcontractors required very close monitoring to make certain that this approach was followed. To many subcontractors the ANIP philosophy of stating the requirements clearly and defining the problem before proceeding with the solution was an initial drudgery. Many capable people, constrained to work in this manner, became mildly frustrated and impatient with the Navy's and the coordinator's insistence on this approach. However, the end result justified the procedure by eliminating many divergent and irrelevant investigations and by pin-pointing the areas in which the research should be emphasized.

In general, subcontract work was initiated by a specification prepared and submitted to industry by Douglas Aircraft Company. The specifications were distributed (1) to firms having a demonstrated capability in the areas of interest, and (2) to firms whose eagerness to participate, though unsupported by proved productive potential, indicated an idea source that could not wisely be ignored. Because of this Douglas-conceived disposition to welcome constructive suggestions from all interested parties, distribution of the specifications was fairly extensive. Via such unrestricted apprisal, an awareness of the program was extended industry-wide.

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When proposals were received in response to a specification, such proposals were evaluated by the coordinator, not only on technical and financial grounds, but on how well the bidder's line of thought indicated an understanding of the philosophy involved and the degree to which this affirmed his ability to solve the problem. The coordinator submitted an evaluation report together with recommendations to the Scientific Officer, who, upon approval by the Working Group, directed that a subcontract be negotiated and the work begun. Contract Administration involved both the financial and technical coverage.

While research work can be programmed as to definite amounts of money and time, results can not. Since the Army-Navy Instrumentation Program had definite results in mind, the research subcontracts occasionally ran into difficulty when attempts were made to solve problems which were too far beyond state-of-the-art realization and thus the final results were not conclusive. On the whole, however, subcontractors were successful as demonstrated by the tangible results of the Army-Navy Instrumentation Program.

The Administration phase of the Army-Navy Instrumentation Program fixed-wing research effort involved many different kinds of tasks. The bulk of the activity took place in the area which may be more appropriately termed management than coordination. The coordinator kept the Scientific Officer informed of all developments as they arose and also submitted formal periodic progress reports covering all aspects of the program. After the last ANIP Symposium (held in 1959), funding limitations necessitated the curtailment of many information disseminating media. As a result, many of the advances in the state of knowledge or art made under ANIP since 1959 are less widely known. People who have need-to-know and who have development application for this information may not have been made aware of the new information. The program value has thus been reduced.

Program funding has been so reduced that no new work could be started after 1961. Present funding is such that only one or two major contracts were sponsored at one time or, alternatively, several smaller contracts. Thus, the need for a coordinator to assist the Navy in the few remaining major programs was reduced more and more and in August 1962 the Joint Working Group took over complete responsibility for all such activity under the Army-Navy Instrumentation Program.

Characteristically, research projects that have proven the feasibility of an approach require an increased funding rate as the project moves toward the prototype model and pre-production phase. In order, then, that these small projects may be carried through to the point where major results are made available for operational use, adequate funding must also be available. Funding limitations that require work to be stretched out over a long period of time result in loss of effectiveness and efficiency.

CONCLUSIONS

The fixed-wing portion of the Army-Navy Instrumentation Program has been a fascinating and challenging activity. In retrospect, the ANIP effort has made many tangible contributions and offered subtle insights to the field of interdisciplinary research in man-machine systems. The success of such a program can be measured not only by contributions to the state of art in man-machine technology but also by the effective organizational concept that made the program possible. To bring together the numerous technologies involved in this system development and have them function in a team effort, it was necessary to install in all contributors a systems philosophy of operation wherein life and physical scientists, and engineers of all specialities, worked together toward a common goal.

It was the intent of the Office of Naval Research that the widest possible dissemination of information developed under the program be made, in order that the maximum benefit to the using agencies and to industry be obtained. To this end over 300 reports, three films and numerous exhibits describing the ANIP activities have been prepared by Douglas and its subcontractors. The majority of these are referenced throughout this report. Table III lists the area of technology supported under ANIP sponsorship with the responsible team member in each area also indicated.

TABLE III.

REPORT INDEX BY CONTRACTORS

Total Number of Reports: 388

Technical Area / Contractor (Number of Reports)	Amelco (2)	ACF Electronics (2)	Bendix (3)	Benson-Lehner (3)	Control Instruments (7)	DeFlorez (4)	Documentation, Inc. (3)	Dodco (22)	Dunlap (57)	Federal Telecommunication Laboratory (4)	General Electric (25)	Human Factors Research (6)	Institute for Research in Human Relations (3)	Kaiser (28)	Lear (2)	Litton (45)	Lockheed (1)	Melpar (4)	Minneapolis-Honeywell (17)	Motorola (4)	Norden (6)	Sperry (13)	Servomechanisms (21)	Varo (18)	Young (5)	Douglas (83)
DISPL HUMAN FACTORS						●			●		●	●	●						●							●
SYSTEM ANALYSIS	●					●		●		●					●	●		●								●
DISPLAY MEDIA														●								●				
DATA PROCESSING	●	●						●			●			●		●						●				
SENSORS			●	●	●														●	●	●		●		●	
MATERIALS														●		●							●	●		●
CIRCUITRY														●		●						●	●	●		●
SIMULATION																	●									●

One measure of success of the program is the number of concepts and equipments developed under its direction which have found their way into operational use or whose support has been taken over by the various development agencies and Government laboratories. Some of the more noteworthy of these are:

Acceptance of the basic display concept for installation in the A2F.

The application by Litton of the T2V(RV-1) computer advancements to a series of production machines for the Grumman A2F, MADC-AIDE IV developmental program, Grumman W2F, the Airborne Tactical Data System (an airborne CIC), and the Marine mortar fire control computer. Production amounted to several hundred million dollars worth of equipment.

The application by Honeywell of the MIG gyro to missiles and inertial platforms for aircraft and space use.

Douglas Contract for the development application of ANIP in the form of a contemporary system installed in an Army light aircraft for operational evaluation of both concepts and equipment (AAAIS designation).

Establishment of an ANIP-oriented program within the FAA research and development group for improvement of instrumentation for civil light aircraft, both private and corporate.

Kaiser production of a developmental model of their all-electronic contact analog generator for NADC for evaluation prior to the A2F production effort at Grumman.

Avion receipt of a development contract to produce a navigation display system for the Army, to be part of the AAAIS program equipment in-work at Douglas.

Rapid-scan radar system by David Young and Associates accepted by the Army for development of an airborne model for evaluation of potential use.

The particle gyro research by Motorola supported by the Army for production of an airborne model for further evaluation.

The Kaiser flat tube investigated by the Army for battlefield command post display in connection with project Michigan and a model provided to the FAA for use in traffic control and control tower applications.

Application by Servomechanisms of their thermoelectric research to investigations of high performance thermoelectric devices and their production feasibility for the Bureau of Ships (Contract NObs 96367) and the Army (Picatinny Arsenal Contract DA-04-495-ORD-1816).

Servomechanisms development of a series of stepping registers and drive circuitry for a classified program sponsored by the Army Ordnance Missile Command (Huntsville, Alabama) (Contract DA-04-045-ORD-3573).

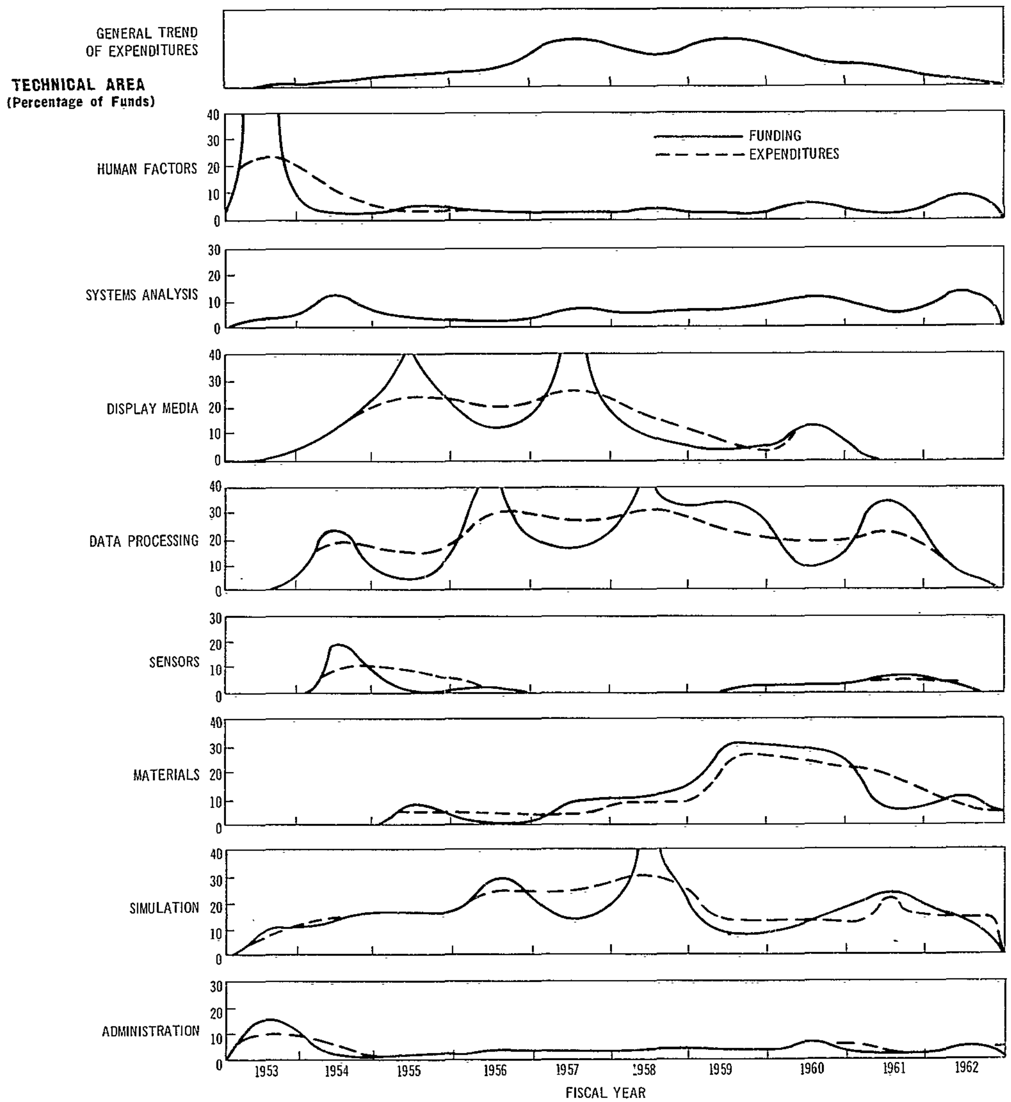
Varo application of their microcircuitry research towards a series of physiological monitoring sensors for Army Chemical Corp. at Edgewood, Maryland.

The remainder of the results, substantially the largest portion, can only be considered contributions to the state of knowledge at present. The real proof of success, acceptance, will only be realized as future utilization is made of the data by other research and development agencies.

A number of other extrapolations of the program technical and management effectiveness can be obtained by plotting both the absolute and relative distribution of ANIP funds for the fiscal years 1953 through 1962 against the general areas of technology described in previous sections. Table IV presents a chart of these percentages:

(Solid line curves are the actual percentages of each fiscal budget applied to that technical area. Dashed line curves are the normalized percentages due to subcontracts that were out of phase with the fiscal year or were programs extending longer than one year. The solid curve in the "fiscal year" column represents the total funding per year. This last curve is indicative more of program enthusiasm and support than of technological problems, since problems occur in a random fashion and must be solvea, regardless of the funding level. Greater support may provide only a quicker or more substantial solution.)

TABLE IV. DISTRIBUTION OF FUNDS



The trends for emphasis of effort can be observed by analysis of the curve data points for each year. The significant events per year are these:

1953 ...... The start of the program....initial human factors effort to gather basic information and display requirements ....the first symposium and brochure for presentation of program goals to government and industry....initial equipment purchased and installed at Douglas for laboratory demonstration of program concepts....systems analysis groups set up the technical format for the research by establishing the man-machine pictogram and related analysis tools.

1954 ...... First system feasibility studies by Douglas and subcontractor systems analysis....specifications prepared and contracts let for first component studies in the key man-machine areas of sensors and data processing.... consideration of Kaiser-Aiken flat cathode ray tube as possible answer to replacement of information missing in real world by synthetic means in the aircraft.

1955 ...... Advances in flat tube, central computer, and contact analog generator gives impetus to RV-1 (First Research Vehicle) flight demonstration plans with purchases of these equipments and design of flight installation.... first concept of microcircuitry explored.

1956 ...... Continued effort to complete RV-1 vehicle and equipment....start of refined human factors requirements leading to RV-2....transparent phosphor problems appear in flat tube program.

1957 ...... RV-1 flight program underway....extensive system analysis, display, and computer studies looking into advanced ideas preliminary to RV-2....problems of basic materials nature appear in display and computer studies leading to further investigations....microcircuitry components envisioned for RV-2 computer; design study underway.

1958 ...... A similar level of effort as in 1957 except that the flat tube work is curtailed in favor of new contact analog and navigation display studies as part of RV-2 program.

1959 ...... A deeper penetration into basic studies of human factors and materials due to: (1) decision not to physically implement an RV-2 vehicle; (2) fundamental material building blocks for all systems envisioned; and (3) many human factors questions about basic display concept unanswered prior to fabrication of contact analog and navigation display units.

1960 ...... First large cut in program support....1959 basic research areas reinforced and hardware programs cut back to match funding situation.

1961 ...... Douglas programs of human factors, simulation and systems analysis to keep study level research going in all areas....more curtailment of hardware due to relatively greater expense of hardware programs as compared to laboratory research and analysis.

1962 ...... Increased emphasis on Human Factors, basic materials, and systems analysis even though funding has been halved again....subcontract system component research almost completely terminated....simulation geared to human factors experiments rather than demonstration work....display generation equipment developed at General Electric and delivered to Douglas preparatory to experimental analysis of contact analog in 1963....coordination function at Douglas terminated with ONR absorbing the responsibility.

1963 ...... Contract terminated February 17, 1963....Electronic Display Equipment returned to General Electric.

In conclusion, it is not to be expected that a program as broad in concept as the ANIP effort would be free of problems. While excellent support was provided by the Air Branch of the Office of Naval Research, it might be helpful for the direction of other similar programs in the future, to sound two notes of caution based upon the experiences encountered.

1. Budget fluctations from year to year as noted in Table II made planning difficult. Maintenance of interdisciplinary research requires that each major area be supported continually. Team effort suffers if areas are alternately started and stopped. Coordinator efforts to distribute contracts not coincident with the fiscal year provided a partial buffer. Regardless of the absolute level of funds, this buffering was not as effective when large up or down changes were made during some fiscal years. In future programs of this type, funds should be programmed on at least a two- and ideally a five-year basis. Research problems and solutions can not be scheduled but the effort directed toward them in a given area can be.
2. Outstanding research and development areas are not always found within the same organization and steps should be taken to divorce the study programs from the hardware implementation.

   Several examples occurred during the course of the program where excellent ideas or concepts were generated by research and study groups but when these same groups were asked to implement their concepts for more than feasibility models, the results were not as successful as if a more production-oriented organization had performed the work.

The fixed-wing portion of the ANIP program has spanned a period of ten years from its inception in September of 1952 to the present. It has demonstrated the implementation of the philosophy that all aspects of the relationships between man and his vehicle should not be considered individually as either man or vehicle, but together in a system designed to meet a given set of requirements involving both. Basic requirements must be firmly and correctly established before problem solutions are attempted. In its practical aspect ANIP has been a working plan and organization to exploit the program philosophy in solving, through research, the problems arising from complex man-vehicle relationships, and in forcing the state of the art to the point where it can meet established requirements.

The contributions have been many, and the results of the research activities and the philosophy of approach will be found in application for years to come.